WASTEWATER COLLECTION AND TREATMENT SYSTEM SECURITY: CONTAMINANT PRIORITIZATION AND CHEMICAL DETECTION

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In recent times terrorists have targeted US citizens at home or abroad. These attacks have primarily concentrated on infrastructure. The destruction of infrastructure is frequently considered an attack on the U.S. Government and the U.S. economy. Among the most critical infrastructure areas needing protection are the potable water treatment and distribution system and wastewater collection and treatment system. In this time of elevated security and concern over possible terrorist attacks, it has become necessary to prepare emergency response plans for public utilities (including wastewater collection and treatment systems).

A framework was developed to numerically rank chemical, biological, and radiological agents with respect to four end points for wastewater collection and treatment. The end points were worker/public health, process upset, physical damage/destruction, and pass through. The four end points were each evaluated with eight criteria. The eight criteria were availability, potency, persistence, introduction/dispersion, process removal, storability, outcomes, and public perception. A literature review was performed for every contaminant evaluated, to determine a

numerical value between 1 and 5 to assign to each of the criteria. At the completion of this research a basic foundation for the prioritization framework had been developed and used to evaluated 14 contaminants.

In addition to developing the prioritization framework, this researched evaluated current technology for detecting volatile organic chemicals (VOCs) using the man portable Hapsite GC/MS. Six water samples were used to evaluate the detection capabilities of the Hapsite GC/MS in varying qualities of water. The samples included distilled water, drinking water, and river water, and from a wastewater treatment facility, primary effluent, secondary effluent, and mixed liquor from the aeration basin. The six water samples were spiked with nine VOCs, at concentrations of 1, 10, and 50 ppb, and analyzed with the Hapsite GC/MS. The observed results indicate that there was a false, low concentration measured in the primary effluent. A false low was also observed in the mixed liquor for select VOCs, depending on their octanol-water partition coefficient. The temperature of an analyzed water sample could affect the instrument's detection capabilities.

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PREFACE

Foremost, I would like to thank Leonard Casson for giving me the opportunity to participate in this research project. His guidance and direction kept me focused throughout my tenure. The friendship that has been established will last far beyond my time at this institution.

Stanley States was an integral part of both the framework development and laboratory analysis. His knowledge and experience was a valuable asset throughout this research.

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Also, I would like to thank Richard Chevetta, of Alleghany Valley Joint Sewer Authority, for his cooperation and assistance in collecting wastewater samples, and Bill Burnard, from Inficon, for driving from Cleveland to assist in the setup and optimization of the Hapsite GC/MS.

I would especially like to thank my parents for their love, encouragement, and support throughout my education.

1.0 INTRODUCTION

In recent times, terrorists have targeted US citizens at home or abroad. These attacks have primarily concentrated on infrastructure. Examples of these targets include the federal building in Oklahoma City, the World Trade Center in New York, the Pentagon, some postal facilities, congressional offices, and two U.S. embassies in Africa. The destruction of infrastructure is frequently considered an attack on the U.S. Government and the U.S. economy.

Among the most critical infrastructure areas needing protection are the potable water treatment and distribution system and wastewater collection and treatment system. There is no need to explain the magnitude of the terror that would be experienced in a community if people were to wake up one morning and find out that they could not use the drinking water or wastewater system. During natural disasters such as hurricane Andrew, Katrina, and Rita, local areas have had to resort to the use of bottled water and portable toilets for periods of time however during a wide spread terrorist attack, large population areas as well as hospitals, nursing homes, and similar facilities might be severely affected for extended periods of time.

In this time of elevated security and concern over possible terrorist attacks, it has become necessary to prepare emergency response plans for public utilities (including wastewater collection and treatment systems). In order to prepare these plans, it is first necessary to perform a vulnerability assessment to help determine possible modes of terrorist attacks and the possible outcomes of those attacks. The overall objective of the research reported herein is to develop a

prioritization method for chemical, biological, radiological, and flammable agents of concern for a wastewater collection and treatment systems. In addition, the ability of current technology to detecting Volatile Organic Chemicals (VOCs) in wastewater during various stages of treatment will be investigated.

The overall objective, discussed above, can be divided into the following specific objectives:

- Develop a contaminant Universe for wastewater collection and treatment systems.
- Develop and validate a prioritization frame work for identifying agents of concern for use in this project and USEPA; and
- Determine current detection capabilities for VOC contamination in wastewater collection and treatment systems using the Hapsite portable GC/MS.

This research is part of a larger funded research project that has the following objectives:

- Develop a further understanding of the nature of the wastewater contamination issues and concerns;
- Obtain information that can be used to guide and inform response planning to deal with intentional or accidental contamination/destruction of the wastewater infrastructure;
- Provide a basis for the development of an analytical approach for evaluating wastewater collection and treatment systems suspected of being contaminated with an unidentified, harmful substance (the potential difficulties associated with the complex wastewater

matrix provides analytical challenges different from those encountered in drinking water samples);

- Provide a basis for development of decontamination/remediation methods for wastewater collection and treatment systems that may be contaminated with harmful substances; and
- Focus research efforts on the most pressing needs by identifying knowledge gaps regarding basic properties, analysis and detection of possible contaminants in wastewater collection and treatment systems for the highest priority contaminants.

There are no known previous terrorist attacks on wastewater infrastructure however there have been several accidental incidents that could show the effects of an intentional attack. These accidental incidents demonstrate the severity of an attack on a wastewater treatment plant or collection system.

2.0 BACKGROUND

The idea of targeting a cities wastewater collection and treatment system does not immediately seem likely. However, as a government owned utility it could be a soft target for a terrorist attack. Disrupting the functions of a wastewater treatment plant may also cause public health concerns. If a treatment plant were to be taken off line it is likely that some if not all the wastewater would be diverted directly into the release point water way causing further public health concerns. Mass casualties may not be the objective of the terrorist. At this time most people associate terrorism with people that will indiscriminately attack innocent people to voice there political or ideological views. There is however the threat of a person whose disgruntlement is with the wastewater treatment plant. The perpetrator may very well be an angry or former employee that is trying to get even or take revenge.

There is also the possibility of secondary effects on a wastewater system from a terrorist event that the wastewater system itself was not the target. If a contaminant is discovered in the drinking water supply or distribution system the most likely action that will be taken will be to flush the drinking water system which will result in the contaminated water being sent to the wastewater system. Chemical, biological, radiological, or flammable agents that were used in an attack could enter the wastewater system by several means including decontamination showers used for mass casualties. The showers at most emergency facilities drain directly into the storm sewers which in many cases are combined sewers.

Biological and chemical contaminates can enter the wastewater system either by them being purposely introduced into the system by a terrorist or as a secondary effect of an unrelated accident or terrorist incident. The concern with these contaminants is the effect they will have on the biological processes that occur in a wastewater system, the potential for harming employees of the treatment plant, and the possibility of the contaminant passing through the system and being released into the surrounding environment. Wastewater treatment facilities use biological processes to treat the incoming sewage.

A chemical contaminant could possibly upset the biological process and cause a loss in its ability to degrade the waste. The untreated waste would then be released into the environment causing further public health concerns. It could take years to clean and remove the contaminate from the treatment system. There is also the concern that the contaminants would not be degraded at all in the treatment process and would be allowed to pass through the system and be released into the environment.

Many of the biological agents that are threats to drinking water systems are not of much concern for wastewater. First several of the agents are already in wastewater and second there are only the exposure routes of inhalation and dermal contact since no one should be ingesting the wastewater.

If the contaminates enter the collection system through storm sewers during decontaminations procedures there will also be mass quantities of decontamination chemicals entering the system with the contaminates. These chemicals are designed to inactivate biological agents and thus could harm the biological process in the wastewater treatment plant.

Example of chemicals disrupting the treatment process:

- 1977 Morris Forman Plant in Louisville Kentucky

In March of 1977 employees of the Morris Forman plant noticed a strong chemical smell that was making them sick (The Hexa-Octe Incident, 2005). After more than a week of investigation it was determined the smell was coming from a mixture of hexachloropentadiene and octachlorocyclopentene. The contaminated treatment plant was shut down and the 100 million gallons of sewage that normally went to the treatment plant each day was diverted around the plant and released directly into the river. It was discovered that the mixture had been dumped into the sewers by a company that was suppose to be properly disposing of industrial waste.

Individuals wishing to target the wastewater utilities will most likely chose a physical attack which could range in a wide range of acts. The simplest and most likely will be acts of vandalism including theft. Potential targets inside the wastewater treatment facility could be stored chemicals on the premises or controls that could alter flows inside the treatment plant. By altering control settings an individual could damage pumps and other infrastructure on site. By exploding chemical storage facilities such as chlorine tanks could be devastating to the surrounding population. To limit the possible damage from the destruction of one of these storage tanks a treatment facility could prepare the disinfection chemicals on site so that there is not a large amount of chemicals being stored on site.

Part of the wastewater system that can be very vulnerable and could have a large impact on the surrounding communities is the collect system. Most sewers are gravity fed and therefore are mostly empty unless during rainfall events. These sewers connect with and pass under most buildings and roads. These systems are usually several meters in diameter and could allow

access, hiding, movement, and storage for terrorists. Sewers are not secured at all; access can be gained through manholes. Sewer systems could be filled with flammable chemicals that when placed in the confined space cause vapors that can build up and explode.

Some examples of sewers exploding from volatile vapors are as follows:

- 1981 Louisville Kentucky
- 1992 Guadalajara Mexico

In the morning of February 13th 1981 a car passing under a railroad overpass on Hill Street in Louisville Kentucky was thrown into the air and landed on its side(The Hexa-Octe Incident, 2005). A spark from the car had ignited a hexane mixture that had built up in the sewer. The hexane entered the sewer system from a spill that had occurred at a soybean processing plant. When the car ignited the mixture it set off a series of explosions that ripped through the street. More than two miles of Louisville streets were left with craters were manholes had been blown out. Several blocks of Hill Street collapsed into the underlying 12 foot sewer. Amazingly no one was seriously hurt however several homes and businesses were damaged.

In April of 1992 in Guadalajara Mexico a sewer explosion killed 215 and injured 1,500 people and damaged some 1,600 buildings (Anguish, 1992). There were at least nine explosions that caused the sewer system to be ripped open into an open trench for more than two kilometers. It was determined that the explosion was caused by a leaking gasoline line that leaked gas into the sewer system.

3.0 MATERIALS AND METHODS: PRIORITIZATION FRAMEWORK

A contaminant universe was assembled to help determine the agents that are of concern with respect to wastewater treatment and adjoining infrastructure. The contaminant universe begins with currents lists of agents that are of concern for drinking water. These include those lists developed by the Centers for Disease Control and Prevention's (CDC) Select Agent list, Water Information Sharing and Analysis Center (Water ISAC), and the United States Army. These lists were developed assuming a primary route of exposure being through ingestion (with some consideration being given to inhalation and dermal contact. Please note, ingestion was not assumed to be an exposure route for wastewater. The primary route of exposure for treatment plant workers and the surrounding community were inhalation and dermal contact. Additional concerns for wastewater security that were not considered for drinking water are, 1) treatment plant process upset, 2) physical damage and destruction, and 3) system pass through to the environment. In addition to the drinking water contaminant lists flammable, radiological, and decontamination agents were also included to account for the above listed concerns. The Occupational Safety and Health Administration's (OSHA) flammable liquids list was used to identify commercially available chemicals that could be used as a fire/explosion threat. A list of decontamination agents was gathered from a publication by William Perry (Perry, 2003). This paper discussed decontamination agents that the EPA has chosen to investigate.

Unlike drinking water with a single end point of public health, wastewater has multiple end points of concern that must be considered when developing a prioritization frame work. The end points are as follows:

·Worker/Public Health

-Inhalation

-Dermal contact

·Process Upset

-Primary treatment

-Secondary treatment

-Tertiary treatment

·Physical Damage/Destruction

-Treatment plant

-Collection system

-Contamination resulting in extensive remediation

·Pass Through

-Receiving Stream

-Downstream drinking water facilities

The first of these endpoints is worker/public health. This end point considers the possibility and effects of a contamination incident with respect to treatment plant workers and the surrounding community. The second end point is process upset inside the treatment plant. This end point evaluates the risk of a contaminant to cause a process upset in the primary, secondary, and tertiary treatment processes. The third end point is physical damage or destruction by fire or

explosion of the collection system and the treatment plant facilities. The final end point concerns a contaminant passing through the treatment system and being released into the environment.

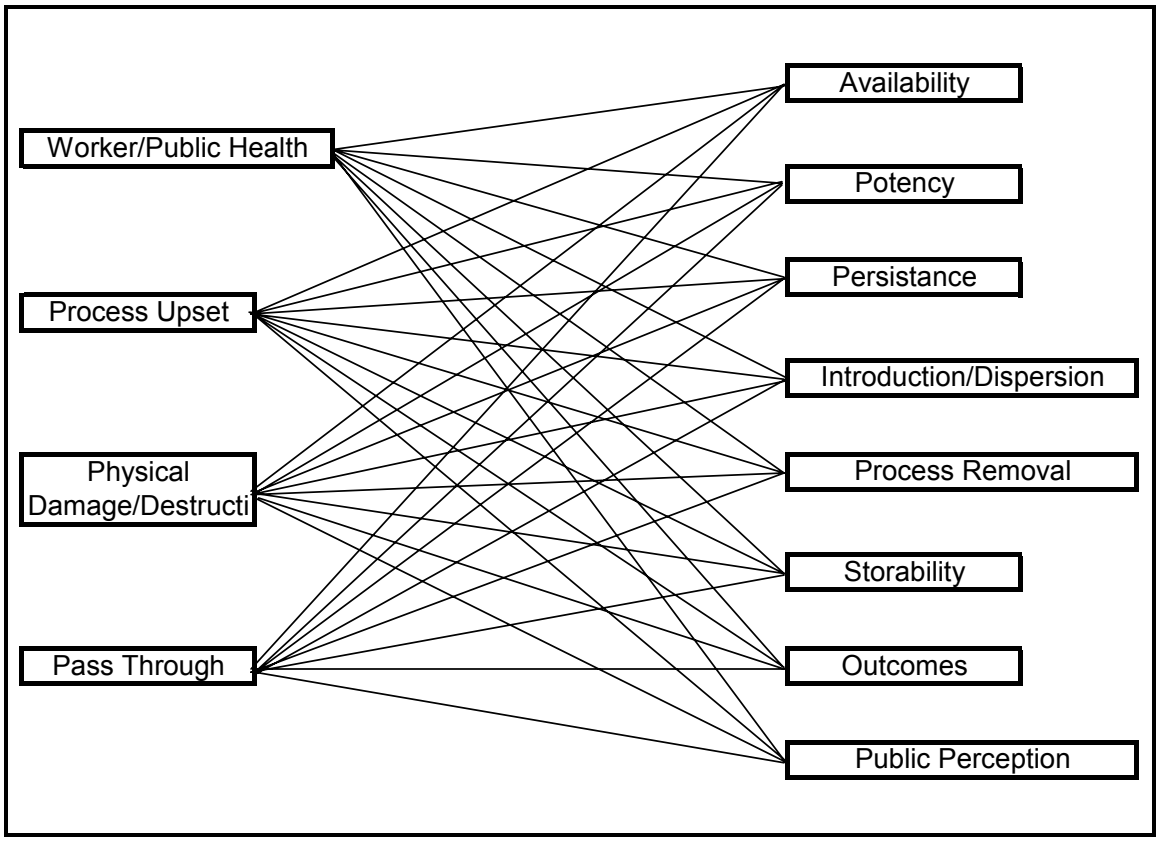


Figure 3.1 Framework Flow Chart

The four end points contain eight criteria for scoring that were based on the drinking water prioritization framework developed by USEPA (Allgeier, 2005). Figure 3.1 shows the relationship between the eight criteria and the four end points. These eight criteria are:

· Availability

· Potency

· Persistence

· Introduction/dispersion

· Process removal (inactivation/treatability)

· Storability

· Outcomes

· Public Perception

Table 3.1 defines each of the criteria that are evaluated for the four end points. A literature review is performed on each individual agent to gather known information such as exposure limits, health effects, lower and upper explosive limits, flash points, and etc. Some of the resources used for the literature reviews were:

· Sax's Dangerous Properties of Industrial Materials

· Handbook of Environmental Data on Organic Chemicals

· Environmental Contaminant Reference Data Book

· Handbook of Toxic and Hazardous Chemicals and Carcinogens

and several sources unique to the individual contaminants including CDC, EPA, and ATSDR (Agency for Toxic Substances and Disease Registry) web sites.

Each of the criteria is assigned a value from 1 to 5, 5 being the most significant, depending on the known data. A value of 3 is assigned for all criteria where no known information exists. Table 3.2 shows the general business rules for assigning numerical values to each of the criteria. Weighting factors were assigned to each of the criteria since some of the criteria are of greater importance than others. The assigned values were then multiplied by the respective weighting factors and added together to establish a cumulative prioritization value. The prioritization equation is listed here as equation 1 and shows how the cumulative prioritization value is

Table 3.1 Criteria Descriptions

Criterion	Description
Availability	The ease with which the contaminant can be obtained, synthesized or harvested from natural, industrial or commercial sources.
Potency	The amount of a contaminant that would be required to contaminate a reference volume of water at a flammable/explosive level or a toxic/infectious dose. This criterion considers the flammable nature, toxicity, infectivity and purity of the contaminant. This criterion may be defined differently for different endpoints.
Persistence	The time that a contaminant remains toxic, infectious or flammable after introduction into a wastewater collection and treatment system.
Introduction/Dispersion	The ease with which a contaminant can be handled and effectively introduced and dispersed into a wastewater collection and treatment system.
Process Removal (Inactivation/Treatability)	The removal or inactivation of a contaminant by typical wastewater treatment unit processes (primary treatment, secondary treatment, disinfection and sludge/biosolids treatment and disposal).
Storability	The time that a contaminant remains toxic, flammable or infectious while in storage (prior to intentional contamination of a wastewater collection and treatment system).
Outcomes (Result of Contamination)	The severity of human health effects for wastewater treatment plant workers exposed to the contaminant or the extent of the physical damage/destruction or process disruption associated with the presence of the contaminant in the wastewater collection and treatment system.
Public Perception	Public perception of the risks associated with the contaminant (e.g., the elevated fear that the public has developed toward anthrax following the US Mail attacks of 2001), the inconvenience associated with the disruption or destruction of the wastewater collection and treatment system, or the presence of wastewater (i.e., using sewage as a weapon).

factor for availability, and then added to the result of the potency value multiplied by W2 and so on. The process continued to cover all eight criteria. A cumulative value was determined for calculated. The numerical value assigned to availability is multiplied by W1, the weighting each of the four end points discussed above. Equation 3.1 shows how these values and weighting factors can be used to determine a ranking value.

$$Score=Av*W1+Po*W2+Pe*W3+ID*W4+Prem*W5+St*W6+Out*W7+Pp*W8 \quad \text{(Eq. 3.1)}$$

Where:

Av = numerical value assigned to the criteria of Availability

Po = numerical value assigned to the criteria of Potency

Pe = numerical value assigned to the criteria of Persistence

ID = numerical value assigned to the criteria of Introduction/Dispersion

Prem = numerical value assigned to the criteria of Process Removal

St = numerical value assigned to the criteria of Storability

Out = numerical value assigned to the criteria of Outcomes

Pp = numerical value assigned to the criteria of Public Perception

W1 = Weighting Factor for Availability

W2 = Weighting Factor for Potency

W3 = Weighting Factor for Persistence

W4 = Weighting Factor for Introduction/Dispersion

W5 = Weighting Factor for Process Removal

W6 = Weighting Factor for Storability

W7 = Weighting Factor for Outcomes

W8 = Weighting Factor for Public Perception

Table 3.2 Business Rules for Scoring

Criterion	Score	Basis for Score
Availability	1	Contaminant only exists in secure facilities and could not be generated without access to specialized information/equipment.
	2	Contaminant is secured, but precursors may be available and synthesis is possible but difficult.
	3	Controlled material with limited production.
	4	Controlled material with widespread application.
	5	Readily available from commercial, industrial, or natural sources (or easily synthesized).
Potency *(Note, potency tables have been developed for LD_{50}, Flashpoint, etc. similar to the ID_{50} information shown here and the flammable potency chart on Page 6)*	1	High ID_{50}, High Flashpoint, High Lower Explosive Limit, High LD_{50}, High LC_{50} (e.g., ID_{50} > 100,000 microbes per ml)
	2	ID_{50} between 10,000 and 100,000 microbes per ml
	3	ID_{50} between 1,000 and 10,000 microbes per ml
	4	ID_{50} between 100 and 1,000 microbes per ml
	5	Low ID_{50}, Low Flashpoint, Low Lower Explosive Limit, Low LD_{50}, Low LC_{50} (e.g., ID_{50} < 100 microbes per ml)
Persistence	1	Contaminant is known to degrade to harmless end products immediately upon contact with water or wastewater.
	2	Contaminant remains viable in water or wastewater for up to two hours.
	3	Contaminant remains viable in water or wastewater for between two hours and one day.
	4	Contaminant remains viable in water or wastewater for between one day and one week.
	5	Contaminant remains viable in water or wastewater for more than one week, or produces more hazardous end products in water and wastewater than the initial contaminant.

Table 3.2 (Continued)

Criterion	Score	Basis for Score
Introduction/Dispersion	1	Difficult to introduce and specialized equipment is required to introduce or disperse the contaminant.
	2	Industrial equipment is required to introduce or disperse the contaminant.
	3	Commercial equipment is required to introduce or disperse the contaminant.
	4	Household equipment is required to introduce or disperse the contaminant.
	5	Easily introduced and no equipment is required to introduce or disperse the contaminant. The contaminant is easily introduced and dispersed.
Process Removal *(Inactivation/Treatability)*	1	Contaminant is removed from the wastewater in the pretreatment or primary treatment processes.
	2	Contaminant is removed from the wastewater in the biological treatment process/secondary sedimentation
	3	Contaminant is removed or inactivated by conventional wastewater treatment disinfection processes. *Unknown Process Removal = 3*
	4	Contaminant is only removed or inactivated by tertiary treatment or specialized unit processes.
	5	Contaminant is not removed during wastewater treatment unit processes.
Storability	1	Not capable of being stored
	2	Half-life/infectivity of the contaminant in storage is less than 1 day.
	3	Half-life/infectivity of the contaminant in storage is between 1 day and 2 weeks.
	4	Half-life/infectivity of the contaminant in storage is between 2 weeks and 6 months.
	5	Half-life/infectivity of the contaminant in storage is greater than 6 months.
Outcomes (Result of Contamination, additional outcomes have been developed to describe the extent of human illness and the possible outcomes of pass through)	1	No adverse effect expected.
	2	Minor effects expected. Simple or normal operational adjustments are required to deal with the contaminant.
	3	Manageable effects expected. Treatment processes must be altered or changed. No remediation is required.
	4	Serious effects expected. Public notification is required. Treatment plant processes are upset and remediation is required.
	5	Catastrophic effects expected. Treatment
Public Perception	1	The public is unaware of the substance or problems with the substance.
	2	Common substance not linked to terrorist activities
	3	Exotic substance not linked to terrorist activities
	4	Common substance linked to terrorist activities
	5	Exotic substance linked to terrorist activities

In order to establish a scoring system for determining the potency of flammable agents two factors were examined. These two factors are the flash point (the temperature at which vapors are produced) and the lower explosive limit (the lowest percent volume in air of a vapor that can explode). A two dimensional table was developed as shown in Table 3.3, so that one score can be determined for the prioritization framework. The scoring chart is a grid that allows the user to compare the two factors and determine the danger of explosion relative to the wastewater prioritization frame work, see Table 3.3. The upper explosive limit (the highest percent volume in air of a vapor that can explode) was not used for determining a potency score because it was assumed that if flammables vapors are present above the upper explosive limit, these vapors will drop into the explosive range as the vapors disperse through the collection system or treatment processes.

To develop this table, relative sewer temperatures were established from Metcalf and Eddy's Wastewater Engineering: Treatment and Reuse (Tchobanoglous, 2003) and the US Army Civil Engineering Corp manual TM 5-852-5/AFR 88-19, Volume 5. Metcalf and Eddy state that the temperature range within US sewers is between 3 and 27^{o}C depending on the geographic location (Tchobanoglous, 2003). The US Army manual lists a temperature of 50^{o}F (10^{o}C) as a minimum temperature for many cold weather wastewater facilities.

To develop the explosive scoring table a flash point factor of 1 through 5 was assigned to temperature values ranging from less than -20^{o}C to greater than 180^{o}C. The temperature of 10^{o}C and below is given a flash point factor of 5. This assignment was based on the idea that 10^{o}C is the lowest expected temperature for sewers in the United States. The temperature range of 20^{o}C to 30^{o}C is assigned a flash point factor of 4. The temperature of 40^{o}C and greater has been assigned a flash point factors of 3 through 1 with the intervals being determined subjectively.

The lower explosive limit (LEL) is listed for the values of less than 1 through greater than 12. Most flammable LELs are located within the range of 1 to 12. A LEL factor of 1 through 5 is assigned to the LELs in 3 percent increments with an LEL of less than 1 being a 5 and greater than 12 being a 1. The LEL factor listed on the x axis of the table is added to the flash point factor on the y axis and is then divided by 2 and the score is then rounded up to the next whole integer, as seen in Equation 3.2.

Flammable Potency = (Flash Point Factor + LEL Factor) / 2 (Eq. 3.2)

Table 3.3 Flammable Contaminant Potency Scoring Chart

Flash Point Factor	Flash Point °C	<1	1	2	3	4	5	6	7	8	9	10	11	12	>12
1	> 180	3	3	3	3	3	3	2	2	2	2	2	2	1	1
1	170	3	3	3	3	3	3	2	2	2	2	2	2	1	1
1	160	3	3	3	3	3	3	2	2	2	2	2	2	1	1
1	150	3	3	3	3	3	3	2	2	2	2	2	2	1	1
1	140	3	3	3	3	3	3	2	2	2	2	2	2	1	1
1	130	3	3	3	3	3	3	2	2	2	2	2	2	1	1
1	120	3	3	3	3	3	3	2	2	2	2	2	2	1	1
1	110	3	3	3	3	3	3	2	2	2	2	2	2	1	1
2	100	4	4	4	3	3	3	3	3	3	2	2	2	2	2
2	90	4	4	4	3	3	3	3	3	3	2	2	2	2	2
2	80	4	4	4	3	3	3	3	3	3	2	2	2	2	2
3	70	4	4	4	4	4	4	3	3	3	3	3	3	2	2
3	60	4	4	4	4	4	4	3	3	3	3	3	3	2	2
3	50	4	4	4	4	4	4	3	3	3	3	3	3	2	2
3	40	4	4	4	4	4	4	3	3	3	3	3	3	2	2
4	30	5	5	5	4	4	4	4	4	4	3	3	3	3	3
4	20	5	5	5	4	4	4	4	4	4	3	3	3	3	3
5	10	5	5	5	5	5	5	4	4	4	4	4	4	3	3
5	0	5	5	5	5	5	5	4	4	4	4	4	4	3	3
5	-10	5	5	5	5	5	5	4	4	4	4	4	4	3	3
5	< -20	5	5	5	5	5	5	4	4	4	4	4	4	3	3
	LEL Factor	5	5	5	4	4	4	3	3	3	2	2	2	1	1

Lower Explosive Limit (Volume % in air)

Score = (Flash Point Factor + LEL Factor)/2

Note: Score is rounded up to next integer

Potency scoring tables were developed for the worker/public health endpoint. These tables are used to reduce subjectivity and increase uniformity of scoring between contaminants when assigning the numerical potency values. The factors for which tables have been developed are:

· Permissible Exposure Limit (PEL)

· Recommended Exposure Limit (REL)

· ID_{50}

· LC_{50}

· IDLH.

The Permissible Exposure Limit is the legal exposure limit established by the Occupational Safety and Health Administration, OSHA, for any 8 hour work shift during a 40 hour work week. The Recommended Exposure Limit is a recommended limit set by the National Institute for Occupational Safety and Health, NIOSH, based on a 10 hour work shift and a 40 hour work week. Table 3.4 is the potency scoring table when using the permissible exposure limit or the recommended exposure limit. Using this table, the numerical value assigned to potency for the end point worker/public health would be a 1 if the PEL or REL was greater than 1,000 ppm. The value of 1, the lowest possible value, represents any concentration greater than 1,000 ppm, because it would be very unlikely for a contaminant to reach such a high concentration and would not be considered much of a threat. The value of 5 represents a PEL or REL less than 1 ppm.

The LC_{50} is the lethal concentration in 50% of animals tested and is related to chemical agents. The potency scoring table is shown in Table 3.5. A LC_{50} greater than 100,000 ppm was assigned a potency value of 1 for the end point of worker/public health and a value of 5 if the LC_{50} is less than 100 ppm.

Table 3.4 Business Rules for Potency Scoring for Permissible Exposure Limit and Recommended Exposure Limit

Score	ppm
1	**> 1,000**
2	**100 to 1,000**
3	**10 to 100**
4	**1 to 10**
5	**< 1**

Table 3.5 Business Rules for Potency Scoring for LC_{50}, Lethal Concentration for 50%

Score	ppm
1	> 100,000
2	10,000 to 100,000
3	1,000 to 10,000
4	100 to 1,000
5	< 100

The ID_{50} is the infective dose in 50% of animals tested and is related to biological agents. The ID_{50} is similar to the LC_{50} except it considers the does of a biological agent to cause infection, while the LC_{50} is a lethal concentration of a chemical. The ID_{50} scoring table, seen in Table 3.6, is identical to the scoring table for the LC_{50} except it has units of microbes per 100 mL instead of ppm.

The IDLH values represent an airborne concentration that is immediately dangerous to life or health. Unlike the PEL and REL, that are based on long term exposure, the IDLH values are for short term exposure, which was of greater concern for this framework. The IDLH scoring table is shown in Table 3.7 and has a concentration range of greater than 5,000 ppm to less than 1 ppm.

Table 3.6 Business Rules for Potency Scoring for ID_{50}, Infective Dose for 50%

Score	ID_{50} Value (microbes per 100 mL)
1	> 100,000
2	10,000 to 100,000
3	1,000 to 10,000
4	100 to 1,000
5	<100

Table 3.7 Business Rules for Potency Scoring for IDLH, Immediately Dangerous to Life or Health

Score	ppm
1	> 5,000
2	1,000 to 5,000
3	100 to 1,000
4	1 to 100
5	< 1

Weighting factors for each of the eight criteria were determined using a two dimensional table which compared the relative importance of each criteria to the other seven with respect to each end point. The method used for determining the weighting factor values is based on the analytic hierarchy and network process discussed in Theory and Applications of the Analytic Network Process: Decision Making with Benefits, Opportunities, Costs, and Risks (Saaty, 2005). In the table the eight criteria are listed both on the horizontal and vertical axis. The criteria on the horizontal axis were compared to the criteria on the vertical axis and it was evaluated to determine if it is equally important or more important to the criteria on the vertical axis. Numerical values of 1, 3, 5, 7, and 9 were used to represent the degree of importance of one criterion over another. These numerical values and their corresponding definitions are from the

previously mentioned book by Thomas L. Saaty (Saaty, 2005). The values and their corresponding definitions are as follows:

· 1 was equal importance

· 3 was moderate importance

· 5 was strong or essential importance

· 7 was very strong or demonstrated importance

· 9 was extreme importance

So for example start with availability on the vertical axis and availability on the horizontal axis in Table 3.9. Since they are the same criteria they are of equal importance and therefore assigned a 1. Moving across the horizontal axis to potency it has been subjectively decided that potency is of moderate importance compared to availability and so assigned a 3. This process is continued across the horizontal axis. When potency on the vertical axis is compared to availability on the horizontal axis the assigned value you be the inverse of the value assigned for when availability on the vertical axis was compared to potency on the horizontal axis in this case it will be 1/3. Once values were assigned to all the criteria comparisons the values were summed horizontally. The sums were then totaled and the sum for each criterion was divided by the total to get a numerical average. The numerical average was used as the weighting factor for that criterion for the evaluated endpoint. The process was repeated for each endpoint and the values are presented in Table 3.8.

Table 3.8 Framework weighting factors

Criteria	Worker/ Public Health	Process Upset	Physical/ Damage Distruction	Pass Through
Availability	0.18	0.24	0.16	0.03
Potency	0.16	0.11	0.06	0.06
Persistance	0.04	0.10	0.05	0.16
Introduction/Dispersion	0.04	0.11	0.06	0.03
Process Removal	0.02	0.09	0.04	0.16
Storability	0.04	0.07	0.02	0.03
Outcomes	0.28	0.26	0.32	0.20
Public Perception	0.24	0.02	0.29	0.33

Table 3.9 Worker/Public Health Weighting Factors

	Availability	Potency	Persistence	Introduction/ Dispersion	Process Removal	Storability	Outcomes	Public Perception	Sum	Normalized Factor
Availability	**1.00**	**3.00**	**7.00**	**7.00**	**9.00**	**5.00**	**0.11**	**0.11**	32.22	**0.18**
Potency	**0.33**	**1.00**	**5.00**	**7.00**	**9.00**	**7.00**	**0.11**	**0.11**	29.56	**0.16**
Persistence	**0.14**	**0.20**	**1.00**	**3.00**	**1.00**	**1.00**	**0.14**	**0.20**	6.69	**0.04**
Introduction/Dispersion	**0.14**	**0.14**	**0.33**	**1.00**	**5.00**	**1.00**	**0.20**	**0.20**	8.02	**0.04**
Process Removal	**0.11**	**0.11**	**1.00**	**0.20**	**1.00**	**0.33**	**0.11**	**0.14**	3.01	**0.02**
Storability	**0.20**	**0.14**	**1.00**	**1.00**	**3.00**	**1.00**	**0.20**	**0.14**	6.69	**0.04**
Outcomes	**9.00**	**9.00**	**7.00**	**5.00**	**9.00**	**5.00**	**1.00**	**5.00**	50.00	**0.28**
Public Perception	**9.00**	**9.00**	**5.00**	**5.00**	**7.00**	**7.00**	**0.20**	**1.00**	43.20	**0.24**
								Sum	179.38	1

1	**Equal importance**
3	**Moderate importance of one over another**
5	**Strong or essential importance**
7	**Very strong or demonstrated importance**
9	**Extreme importance**

4.0 RESULTS AND DISCUSSION: PRIORITIZATION FRAMEWORK

The research performed in this project has compiled literature reviews for 79 contaminants and has assigned numerical values to 14 contaminants. Every contaminant was classified in to three categories. The three categories were radiological, biological, and chemical. The category for chemical contaminants was further divided into three sub-categories, chemical non-flammable, chemical flammable, and decontamination agents. All chemical contaminants were placed into one of the three sub-categories. Figure 4.1 shows the flow chart for chemical classification.

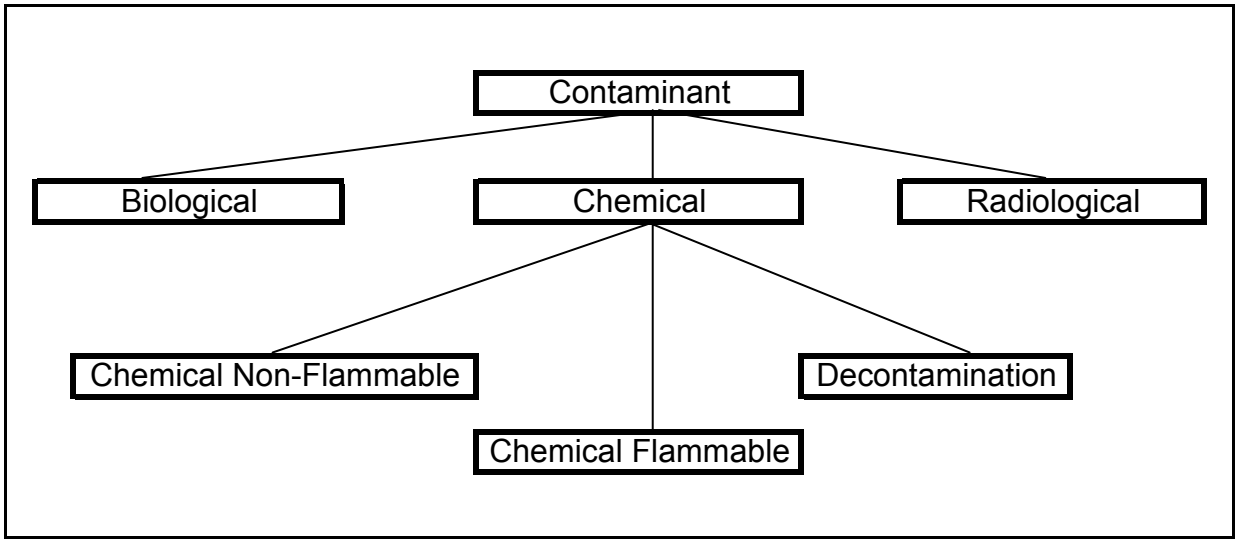


Figure 4.1 Contaminant Category Organization

The contaminants were evaluated using the eight criteria previously discussed for the four end points of worker/public health, process upset, physical damage/destruction, and pass through. Several of the criteria that have been used for evaluating the contaminants remain unchanged through all four endpoints. The criteria that did not change are as follows:

·Availability,

·Persistence

·Introduction/Dispersion

·Process Removal

·Storability

·Public Perception

Availability is the ease at which a contaminant could be obtained and therefore does not change with respect to the end point. Persistence and storability are dependent on the physical, chemical, and biological properties of the contaminant. Introduction/dispersion describes the ease at which the contaminant can be introduced into a wastewater collection system or treatment facility. Process removal indicates if, and if so, where a contaminant is expected to be removed through the treatment processes. The criteria of public perception takes into account the public reaction to a contaminant being found in the wastewater collection system or the treatment facility. The nature of these criteria makes them independent of endpoints and therefore has no change to the numerical values assigned throughout all four endpoints. Though the numerical values remain the same for these criteria the weighting factors associated with each criterion have changed with respect to the endpoints. The only two criteria that changed between endpoints are potency and outcomes. Potency is dependent on the endpoint because it indicates the quantity of a contaminant to cause human sickness or death for worker/public health,

disruption of the treatment process for process upset, a fire or explosion for physical damage or destruction, and adverse effects of aquatic life or down stream drinking water facilities for pass through. Outcomes describe the possible results of a contamination incident and as such by definition changed per endpoint. Figure 4.2 shows how the eight criteria relate to the four endpoints. The criteria of potency and outcomes are boarder with an oval to indicate that they are the two criteria that change with respect to endpoints.

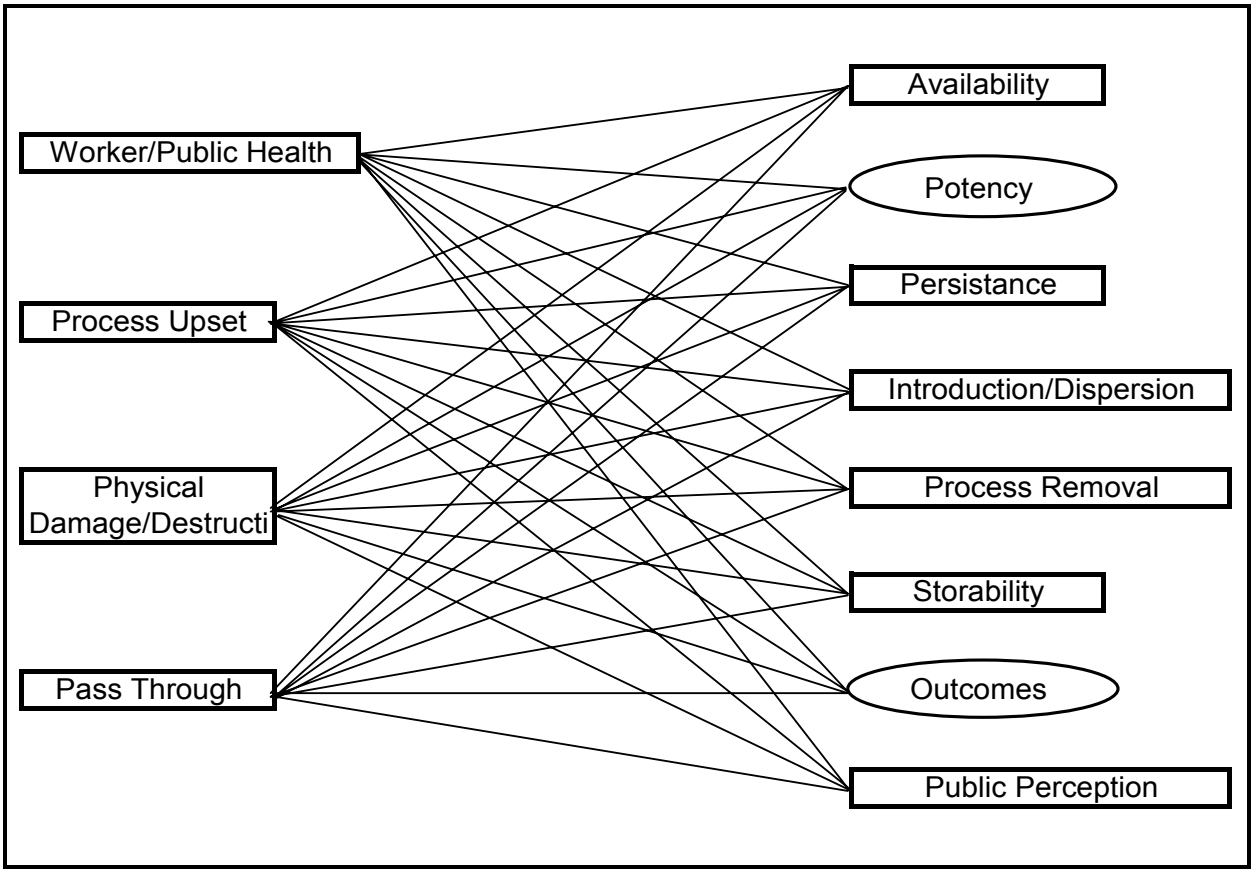


Figure 4.2 Framework Flow Chart

This research has developed scoring tables for the criteria of potency for the endpoints of worker/public health and flammability for physical damage/destruction. All other criteria are scored subjectively using the business rules for scoring that have been developed as a guide and the information collected in the literature review of each contaminant. The criterion of introduction/dispersion has been assigned a value of 5 for all contaminants evaluated except for the radiological contaminants which have been assigned a value of 3. The criterion of introduction/dispersion was assigned a value of 5 for most contaminants because with a combined sewer system a contaminant could be easily introduced through a storm drain. The radiological contaminants would require specialized equipment for handling and dispersing the contaminant.

Tables were created for each of the four end points for every contaminant evaluated. Separate tables were created for each of the end points. The tables list the eight criteria and their corresponding weighting factors with respect to end point. Information related to the eight criteria that is gathered in the literature review for the contaminant is listed to justify the values that are assigned. The numerical values that are assigned and the composite score that is calculated using the aforementioned Equation 3.1 are shown. Table 4.2 is the table representing the framework results for the contaminant, hexane, for the end point of worker/public health. Hexane was evaluated to be readily available and was assigned a value of 5. The recommended exposure limit (REL) for hexane is 50 ppm (Hexane, 2005) Using the developed REL scoring table, Table 3.3, a value of 3 was assigned. Hexane would float on the surface of water and quickly evaporate causing it to be assigned a value of 2 for the criteria of persistence (ToxFaq, 2005). As previously discussed, hexane was assigned a value of 5 for introduction and dispersion, assuming a combined sewer system. Hexane was assigned values of 4 for both

process removal and storability. A value of 3 was assigned for the criteria of outcomes because the side effects from hexane exposure are just headaches, nausea, confusion, and dizziness (Hexane, 2005). The general public is familiar with hexane and does not associate it with terrorism; therefore a value of 2 was assigned for the criteria of public perception. Using Equation 1 a composite score of 3.2 was calculated.

Only the criteria of potency and outcomes change with respect to the end point and as a result Tables 4.3, 4.4, and 4.5 are identical to Table 4.2 except for the two criteria. Table 4.3 is the table developed for process upset. The potency to cause a process upset with hexane is unknown, as was the possible outcome on the treatment process from a hexane incident at a wastewater treatment plant. As a result of the unknown concentration and outcome, both criteria were assigned the default value of 3. The composite score for the end point of process upset was 3.7. Table 4.4 is the table for the end point physical damage/destruction. The potency value was determined by the known flash point and lower explosive limit and using Figure 3.2, the flammable scoring chart. The criteria of outcome was assigned a value of 5 based on the previous incident of the hexane explosion in the sewers of Louisville, Kentucky in February 1981 (The Hexa-Octe Incident, 2005) A composite score of 3.9 was calculated for the end point of physical damage/destruction. Table 4.5 is the table developed for the end point of pass through. Potency was assigned a value of 5 and outcomes received a value of 3 resulting in a composite score of 2.9.

A summary of the composite scores for all 14 evaluated contaminants is shown in Table 4.1. Ethylene glycol received the lowest composite score for both worker/public health and physical damage or destruction. This is not a surprising result since ethylene glycol is used as anti-freeze for cars and de-icing fluid for airplanes. Ethylene glycol has a low vapor pressure making it

unlikely that it would pose an inhalation risk if present in wastewater and it is poorly absorbed through the skin. Ethylene glycol has a high flash point making it unlikely to produce flammable vapors in the wastewater collection system or treatment facility. Ammonia was evaluated to be the contaminant of lowest risk for process upset. Ammonia is expected to be present in wastewater and therefore the treatment process is designed to remove it from the wastewater stream. Chlorine dioxide ranked as the lowest threat to a wastewater treatment plant for the criteria of pass through. Chlorine dioxide is used in water treatment facilities and is expected to degrade rapidly when in contact with water and form chlorite (ToxFaq, 2005).

Table 4.1 Framework Scoring Results

Contaminant	Worker/ Public Health	Process Upset	Physical Damage/ Destruction	Pass Through
Ammonia	2.8	**2.8**	2.7	2.1
Anthrax	3.8	3.6	**4.2**	**4.1**
Arsenic	3.9	3.8	3.8	3.8
Botulinum Toxin	**4.4**	3.4	3.0	3.6
Cesium 137	3.7	2.9	3.7	3.7
Chlorine Dioxide	3.4	3.2	3.1	**1.9**
Cyanide	4.2	3.9	3.3	4.0
Ethylene Glycol	**2.6**	3.4	**2.5**	2.3
Gasoline	3.6	4.0	4.0	2.8
Hexane	3.2	3.7	3.9	3.1
Kerosene	3.0	4.0	4.0	2.5
Malathion	4.0	4.0	3.3	3.2
Paraquat	3.7	**4.2**	3.5	3.2
Strontium 90	3.7	3.4	3.8	3.8
Minimum	**2.6**	**2.8**	**2.5**	**1.9**
Maximum	**4.4**	**4.2**	**4.2**	**4.1**
Standard Deviation	**0.5**	**0.4**	**0.5**	**0.7**

Botulinum toxin, a known warfare agent, had the highest composite score for the endpoint of worker/public health (Arnon, 2001). According to the calculated weighting factors for worker/public health the criteria of availability, potency, outcomes, and public perception are the most significant, with the latter two being the most important. *Botulinum toxin* had a value of 5 assigned to three of these criteria with only availability receiving a 2. Paraquat has the highest composite score for process upset. Paraquat is a widely used herbicide that is known to be harmful to aquatic life therefore it follows logic that it would be a contaminant of concern when considering process upset.

Bacillas anthracis received the highest composite scores for the endpoints of physical damage/destruction and pass through. Anthrax spores are resistant to chlorination and would either be able to pass through the treatment facility through the water stream or would be concentrated in the biosolids and sent off site, possibly to be land applied, effectively passing through the treatment facility. *Bacillas anthracis* receiving the highest composite score for physical damage/destruction is not as clear as the other results. The weighting factors had a significant role in the final results for the endpoint of physical damage/destruction. There are two significant weighting factors for this endpoint. Those are the weighting factors for the criteria of outcomes and public perception. These two weighting factors are nearly twice that of the next largest weighting factor which is for availability. As a result if a contaminant receives a high numerical value for these two endpoints it could effectively out score another contaminant that receives higher scores for the other six criteria but may not be seen by the public as threatening. A contaminant that has been assigned a numerical value of 5, the highest possible value, for all criteria except public perception would have to receive a value of 3 or greater to surpass anthrax as the greatest calculated threat to a wastewater collection system or treatment

facility for the endpoint of physical damage/destruction. The criteria for worker/public health would also require a value of 3 or greater for the criteria of public perception to surpass *Botulinum toxin* as the highest ranked contaminant. Similar is the criteria of pass through which would require a value of at least 2 for the criteria of public perception even if all other criteria received a score of 5. The public perception of a contaminant would not change the outcome of an event occurring as a result of the presence of that contaminant. It could be argued that the presence of a contaminant that is of high concern to the general public could cause a public outcry for the immediate stop of usage and replacement of the collection system and treatment plant. This would effectively be the same outcome as if the collection system and treatment facility had been destroyed, not to include loss of life. Anthrax could cause such an outcry to occur especially since the spores could remain viable in a water environment for decades.

Table 4.2 Hexane Worker/Public Hexane

Criterion	Worker/Public Health		
	Weighting Factor	Score	Comments
Availability	0.18	5	[HE01]Hexane is a chemical made from crude oil. It is used in laboratories in its pure form. It is also used in solvents to extract vegetable oils and as cleaning agents. Gasoline, quick-drying glue, and rubber cement contain n-hexane.
Potency	0.16	3	[HE02]OSHA PEL is 500 ppm as a an 8 hour TWA. NIOSH REL is 50 ppm as a TWA for up to a 10 hour workday and a 40 hour workweek. [HE07]The 24 hour LC_{50} for a goldfish is 4 mg/l
Persistence	0.04	2	[HE01]It evaporates easily into the air and is broken down in a few days. Most of n-hexane spilled in water will float on the surface and then evaporate. If it is spilled on the ground, most of it will evaporate before it can soak into the soil. [HE04] Solubility in water is 0.000013g/ml at 20^{o}C and the vapor pressure is 17 kPa [HE05]A variety of microorganisms degrade hexane by oxidation mechanisms similar to those that involve the lower homologues. The K_{ow} is 4.11
Introduction/Dispersion	0.04	5	Hexane could be easily introduced into the wastewater collection and treatment system.
Process Removal	0.02	4	[HE02]Contact of n-hexane with strong oxidizing agents should be avoided.
Storability	0.04	4	[HE03]It is highly flammable. Must be stored in tightly closed containers in a cool, well-ventilated area away from heat, strong oxidizers, and sources of ignition.
Outcomes	0.28	3	[HE02]Exposure to 5,000 ppm of n-hexane for 10 minutes causes marked vertigo. Exposure can also lead to dizziness, confusion, nausea, headache, and irritation of the eyes, nose, throat, and skin. Dermal contact results in immediate irritation with blisters following 5 hours later.
Public Perception	0.24	2	The public is familiar with this chemical that has not be associated with previous terrorist activities.
Composite Score		**3.2**	

Comments:

HE01 http://www.atsdr.cdc.gov/tfacts113.html

HE02 http://www.osha.gov/SLTC/healthguidelines/n-hexane/recognition.html

HE03 Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

HE04 http://www.cdc.gov/niosh/ipcsneng/neng0279.html

HE05 Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

HE07 Verschueren, Karel. Handbook of Environmental Data on Organic Chemicals, 4th Edition. 2001.

PEL = Permissible Exposure Limit. The legal exposure limit established by OSHA for TWA exposure in any 8 hour work shift during a 40 hour work week.

REL = Recommended Exposure Limit. The REL is a recommended exposure limit set by NIOSH based on a 10 hour work shift and a 40 hour work week.

TWA = Time Weighted Average. The TWA is a way of measuring the total exposure of a worker to contaminants in work room air in a work day.

Table 4.3 Hexane Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	5	[HE01]Hexane is a chemical made from crude oil. It is used in laboratories in its pure form. It is also used in solvents to extract vegetable oils and as cleaning agents. Gasoline, quick-drying glue, and rubber cement contain n-hexane.
Potency	0.11	3	Unknown
Persistence	0.10	2	[HE01]It evaporates easily into the air and is broken down in a few days. Most of n-hexane spilled in water will float on the surface and then evaporate. If it is spilled on the ground, most of it will evaporate before it can soak into the soil. [HE04] Solubility in water is 0.000013g/ml at 20^{o}C and the vapour pressure is 17 kPa [HE05]A variety of microorganisms degrade hexane by oxidation mechanisms similar to those that involve the lower homologues. The K_{ow} is 4.11
Introduction/Dispersion	0.11	5	Hexane could be easily introduced into the wastewater collection and treatment system.
Process Removal	0.09	4	[HE02]Contact of n-hexane with strong oxidizing agents should be avoided.
Storability	0.07	4	[HE03]It is highly flammable. Must be stored in tightly closed containers in a cool, well-ventilated area away from heat, strong oxidizers, and sources of ignition.
Outcomes	0.26	3	Unknown
Public Perception	0.02	2	The public is familiar with this chemical that has not be associated with previous terrorist activities.
	Composite Score	3.7	

Comments:

[HE01] http://www.atsdr.cdc.gov/tfacts113.html

[HE02] http://www.osha.gov/SLTC/healthguidelines/n-hexane/recognition.html

[HE03] Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

[HE04] http://www.cdc.gov/niosh/ipcsneng/neng0279.html

[HE05] Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

Table 4.4 Hexane Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	5	[HE01]Hexane is a chemical made from crude oil. It is used in laboratories in its pure form. It is also used in solvents to extract vegetable oils and as cleaning agents. Gasoline, quick-drying glue, and rubber cement contain n-hexane.
Potency	0.06	5	[HE02]Flash point is -22°C. Lower explosive limit is 1.1%. Upper explosive limit is 7.5%.
Persistence	0.05	2	[HE01]It evaporates easily into the air and is broken down in a few days. Most of n-hexane spilled in water will float on the surface and then evaporate. If it is spilled on the ground, most of it will evaporate before it can soak into the soil. [HE04] Solubility in water is 0.000013g/ml at 20°C and the vapour pressure is 17 kPa [HE05]A variety of microorganisms degrade hexane by oxidation mechanisms similar to those that involve the lower homologues. The K_{ow} is 4.11
Introduction/Dispersion	0.06	5	Hexane could be easily introduced into the wastewater collection and treatment system.
Process Removal	0.04	4	[HE02]Contact of n-hexane with strong oxidizing agents should be avoided.
Storability	0.02	4	[HE03]It is highly flammable. Must be stored in tightly closed containers in a cool, well-ventilated area away from heat, strong oxidizers, and sources of ignition.
Outcomes	0.32	5	[HE06]Hexane is highly flammable. On February 13, 1981, thousands of gallons of hexane spilled into the sewer lines in Louisville, Kentucky. A spark from a car ignited the gas that had been created in the sewer and more than two miles of streets were destroyed from the explosions.
Public Perception	0.29	2	The public is familiar with this chemical that has not be associated with previous terrorist activities.
Composite Score		**3.9**	

Comments:

[HE01] http://www.atsdr.cdc.gov/tfacts113.html

[HE02] http://www.osha.gov/SLTC/healthguidelines/n-hexane/recognition.html

[HE03] Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

[HE04] http://www.cdc.gov/niosh/ipcsneng/neng0279.html

[HE05] Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

[HE06] http://www.msdlouky.org/aboutmsd/history20.htm

FLASH POINT = The lowest temperature at which a flammable liquid will give off enough vapors to form an ignitable mixture with the air above the surface of the liquid or within its container.

LEL = Lower Explosive Limit. The percentage of vapor in the air below which a fire can't occur because there isn't enough fuel: the mixture is said to be too lean.

UEL = Upper Explosive Limit. The percentage of vapor in the air above which there isn't enough air for a fire: the mixture is said to be too rich.

Table 4.5 Hexane Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	5	[HE01]Hexane is a chemical made from crude oil. It is used in laboratories in its pure form. It is also used in solvents to extract vegetable oils and as cleaning agents. Gasoline, quick-drying glue, and rubber cement contain n-hexane.
Potency	0.06	5	[HE04] Solubility in water is 0.000013g/ml at 20oC and the vapor pressure is 17 kPa HE05A variety of microorganisms degrade hexane by oxidation mechanisms similar to those that involve the lower homologues. The Kow is 4.11
Persistence	0.16	2	[HE01]It evaporates easily into the air and is broken down in a few days. Most of n-hexane spilled in water will float on the surface and then evaporate. If it is spilled on the ground, most of it will evaporate before it can soak into the soil. [HE04] Solubility in water is 0.000013g/ml at 20^{o}C and the vapour pressure is 17 kPa [HE05]A variety of microorganisms degrade hexane by oxidation mechanisms similar to those that involve the lower homologues. The K_{ow} is 4.11
Introduction/Dispersion	0.03	5	Hexane could be easily introduced into the wastewater collection and treatment system.
Process Removal	0.16	4	[HE02]Contact of n-hexane with strong oxidizing agents should be avoided.
Storability	0.03	4	[HE03]It is highly flammable. Must be stored in tightly closed containers in a cool, well-ventilated area away from heat, strong oxidizers, and sources of ignition.
Outcomes	0.20	3	[HE01]It evaporates easily into the air and is broken down in a few days. Most of n-hexane spilled in water will float on the surface and then evaporate. If it is spilled on the ground, most of it will evaporate before it can soak into the soil.
Public Perception	0.33	2	The public is familiar with this chemical that has not be associated with previous terrorist activities.
	Composite Score	**2.9**	

Comments:

[HE01] http://www.atsdr.cdc.gov/tfacts113.html

[HE02] http://www.osha.gov/SLTC/healthguidelines/n-hexane/recognition.html

[HE03] Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

[HE04] http://www.cdc.gov/niosh/ipcsneng/neng0279.html

[HE05] Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

5.0 MATERIALS AND METHODS: INFICON HAPSITE GC/MS

Gas chromatograph compiled with mass spectrometer (GC/MS) has been used in laboratories for many years for environmental characterization and monitoring. The gas chromatograph separates chemical mixtures into individual components which are broken subsequently into ions by an electron beam in the electron impact source module of the mass spectrometer. The ions are separated and detected by the electron multiplier. The resulting mass spectra are unique to individual chemicals and can be identified by comparison to a spectral library. The Hapsite GC/MS was developed by Inficon as a portable gas chromatograph / mass spectrometer designed for detection of volatile organic chemicals (VOCs) in air. The SituProbe Purge and Trap device was added to the original instrument to comprise the instrument used in the research. The Hapsite SituProbe can be submerged directly into water and does not require sample collection equipment. Inside the probe, a nitrogen headspace is created followed by a nitrogen purge. The nitrogen that bubbles through the water sample allows VOCs in the sample probe aliquot to enter into the gas phase and then enter the measurement instrument. A convenient feature of the Hapsite GC/MS was that the sample only came into contact with the probe, such that water samples with a complex chemical matrix were analyzed without contaminating the instrument. The following water matrixes were analyzed using the Hapsite GC/MS:

· Distilled Water

· Drinking Water

· River Water

· Primary Effluent

· Mixed Liquor

· Secondary Effluent

Wastewater grab samples were acquired from the secondary effluent, primary effluent, and the aeration basin (Mixed Liquor) at the Allegheny Valley Joint Sewage Authority wastewater treatment plant in Harmerville, PA. These samples were transported to the Pittsburgh Water and Sewer Authority (PWSA) drinking water treatment plant analytical laboratory. The samples and storage containers were then placed in a water bath to maintain a uniform temperature. Drinking water samples were gathered from the drinking water outlet house at the Pittsburgh Water and Sewer Authority drinking water treatment plant. River water samples were taken from the Allegheny River through a sampling point in the pump house behind the treatment plant. The distilled water used in this research was obtained from a Millipore filtration system in the PWSA laboratory. All water samples are stored at 4 ^{o}C in a cold temperature room when stored overnight. No samples were stored for more than two weeks.

Stock solutions were purchased from Ultra Scientific and stored at an initial concentration of 5000 ppm. Two calibration standards were used in this research. The first standard (Cal-1) consisted of 48 µL of *trans* 1,2-dichloroethylene, ethylbenzene, benzene, and *p*-xylene mixed with 808 µl of purge and trap grade methanol which was 99.9% Assay. The second standard (Cal-2) contained 48 µL of *trans* 1,2-dichloroethylene, styrene, 4 chlorotoluene, 1,3 dichlorobenzene, and *o*-xylene mixed with 760 µL of purge and trap grade methanol solvent. Stock solutions of all nine compounds used to create the standards Cal-1 and Cal-2 were stored in the freezer at the PWSA laboratory to prevent volatilization. Using a syringe that has been

rinsed at least three times with methanol, 808 μL for Cal-1 and 760 μL for Cal-2 of purge and trap grade methanol is transferred into separate vials. A 100 μL syringe was rinsed and used to transfer 48 μL of each of the compounds into the same vial as the methanol, depending on which standard is being made. Before injecting each agent it is important to ensure that the tip of the syringe is submerged below the surface of the methanol in the vial so as to prevent volatilization of the compound. Once the standard has been made, the vial is stored in a cooler with ice packs in order to reduce volatilization while the standard is out of the freezer.

As with all instrumentation, the Hapsite GC/MS must be calibrated prior to sample analysis. The calibration concentrations used were 1, 5, 10, 15, 20, 30, 50, and 70 ppb. Distilled water was spiked with the calibration standard and analyzed at eight concentrations to calibrate the instrument. . The statistical outliers were removed while maintaining at least 5 calibration points including at least one concentration greater than or equal to 50 ppb. The instrument was calibrated separately for experiments 1 and 2 and calibrated once for experiments 3 and 4 for the Cal-1 standard. Table 5.1 lists the dates of each calibration as well as sample collection dates and experiment dates for round 1. The instrument was calibrated once for all four experiments performed with the Cal-2 standard. The analysis method used for the Cal-1 standard consisted of a 60 second purge time and a 10 minute analysis with an isothermal temperature program set at 60 ^{o}C. The method for the Cal-2 standard consisted of a 60 second purge time and a 13 minute analysis at an isothermal temperature range of 80 ^{o}C. The Cal-2 standard was initially analyzed with the method established for Cal-1, however it could was seen from the chromatogram, that all the compounds did not come off the column even with an extended analysis time of 30 minutes. As a result, the analysis temperature was increased to 80 ^{o}C and the analysis time was extended to 13 minutes. The increased time and temperature does not change the instruments

Table 5.1 Experimental dates for Round 1

Experiment	[a]Sample Water Collection Date	[b]Sample Wastewater Collection Date	Experiment Date	Calibration Date
Round 1				
1	9/27/2005	9/27/2005	10/4/2005	10/4/2005
2	10/6/2005	10/10/2005	10/11/2005	10/6/2005
3	10/6/2005	10/10/2005	10/14/2005	10/13/2005
4	10/6/2005	10/10/2005	10/18/2005	10/13/2005

Note:
[a] Sample water includes drinking water and river water
[b] Sample wastewater includes primary effluent, secondary effluent, and mixed liquor

ability to detect VOCs, rather it accelerates the analysis. The increased temperature accelerated the driving off of the compounds from the column. The extended analysis time ensured that there was sufficient time for all the compounds to be driven off the column.

Two experimental rounds were performed; each round consisted of four experiments. All experiments in this research were performed identically except were noted. Round 1 was performed using the Cal-1 standard and round 2 used the Cal-2 standard. Samples were prepare for an experimental trial by agitating thee storage container for each water sample to achieve a uniform suspended solids concentration prior to transferring the needed quantity of the water sample to volumetric flasks. A 500 mL and a 100 mL volumetric flask were used to measure the 600 mL sample volume which was then poured into a modified 2000 mL graduated cylinder. To perform the experiments in this research, a container was needed that had a sufficient diameter so that the probe could fit into the container but also minimize the volume of a water sample required to submerge the probe. A 2,000 mL graduated cylinder has a large enough diameter and only requires 600 mL of a water sample to achieve the proper depth, however it was too long and

narrow for a syringe to be used to spike the samples.. In order for the 2000 mL graduated cylinder to be used, it was required to cut off the top portion of the cylinder at the 1,000 mL mark. The Cal standard was injected directly into the water sample using a syringe and insuring that the tip of the syringe was submerged below the surface of the water, which was impossible prior to removing the top portion of the graduated cylinder. The sample in the cylinder was briefly agitated by swirling the cylinder by hand. A stir bar and plate was not used to help prevent volatilization of the compounds from the water sample prior to the analysis. The Hapsite probe was inserted to begin a run. The same experimental procedures were used to for both Cal-1 and Cal-2.

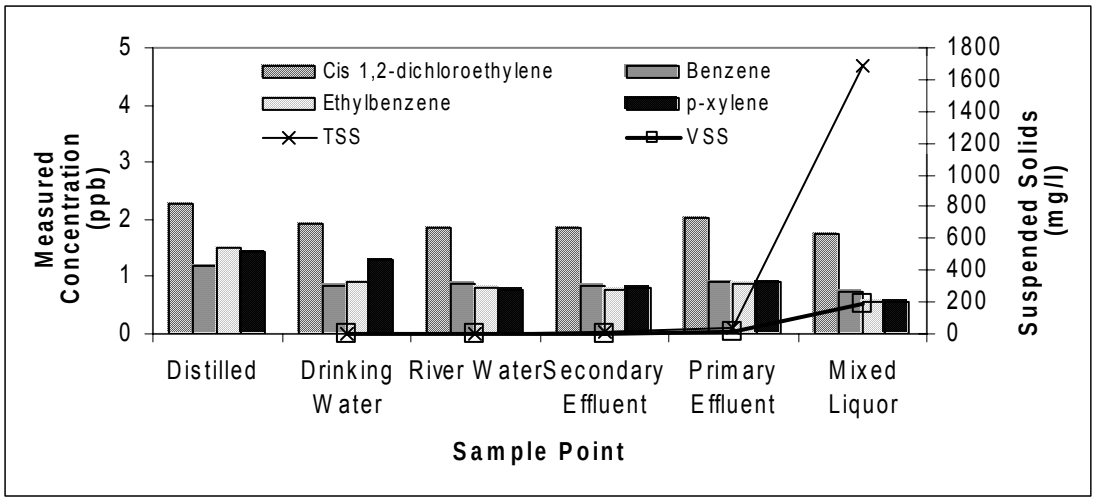
6.0 RESULST AND DISCUSSION: INFICON HAPSITE GC/MS

In this research, the first round of volatile organic chemicals (VOCs) *cis* 1,2-dichloroethylene, benzene, ethylbenzene, and *p*-xylene were analyzed using an Inficon Hapsite GC/MS at concentrations of 1, 10, and 50 ppb. After four experimental runs it was clear that there was a level of consistency in the reported concentrations between experimental runs. There was some deviation in the reported concentrations that is assumed to be error in either the application of the experimental procedures or the normal deviation for this instrument. Experiment 1 for the first round displayed the most significant deviation however the deviation was less pronounced in the reported concentrations of *cis* 1,2-dichloroethylene. This would suggest that the deviation is a result of the instruments capabilities. Further experiments need to be performed to determine the true cause of the deviation. Even with the deviations, all four experimental runs demonstrated the instruments ability to detect the tested VOCs in varying qualities of water.

Figure 6.1 A., B., and C. illustrates the measured concentration of the four VOCs in the six different water samples when spiked at 1, 10, and 50 ppb for Experiment 1. Overlaid on the graph of the reported concentrations are the total suspended solids (TSS) and the volatile suspended solids (VSS) concentrations. The six water samples are listed left to right by increasing suspended solids concentrations. Figure 6.1 A. shows the results for the samples spiked at 1ppb. It is observed that for all samples the *cis* 1,2-dichloroethylene had a reported concentration of almost 2 ppb twice that of the other four VOCs tested. Figure 6.1 B. is the

graph representing the results for the samples spiked at 10 ppb. *Cis* 1,2-dichloroethylene and benzene were detected at slightly higher concentrations of 7.31 ppb and 6.95 ppb, than did the ethylbenzene and the *p*-xylene at 6.13 ppb and 5.34 ppb. Distilled water, drinking water, river water, and secondary effluent samples yielded similar results to each other. There was a decrease in the measured concentrations of all four VOCs at each spiking level in the primary effluent. Oppositely the mixed liquor had the highest reported concentration of all six water matrixes. Figure 6.1 C. shows the results for when the samples were spiked at 50 ppb. The *cis* 1,2-dichloroethylene reported approximately 48.1 ppb in the distilled water sample. The other three chemicals measured sequentially higher concentrations, i.e. benzene at 63.6 ppb > *cis* 1,2-dichloroethylene, ethylbenzene at 70.4 ppb > benzene, the *p*-xylene measured the largest concentration of 76.4 ppb. This trend was also observed in drinking water sample except with smaller differences between VOCs, so that the reported concentration of the *p*-xylene was 63.4 ppb. The river water, secondary effluent, and primary effluent reported similar results to each other with the *cis* 1,2-dichloroethylene having about 40 ppb and the benzene, ethylbenzene, and *p*-xylene measuring 45 ppb. There was a decrease in the measured concentrations recovered from the mixed liquor in comparison to the other five water matrixes. When considering Figure 6.1 A., B., and C. there does not appear to be any significant difference between the water matrixes except for aforementioned mixed liquor in B. and the distilled water in C. as noted.

A.



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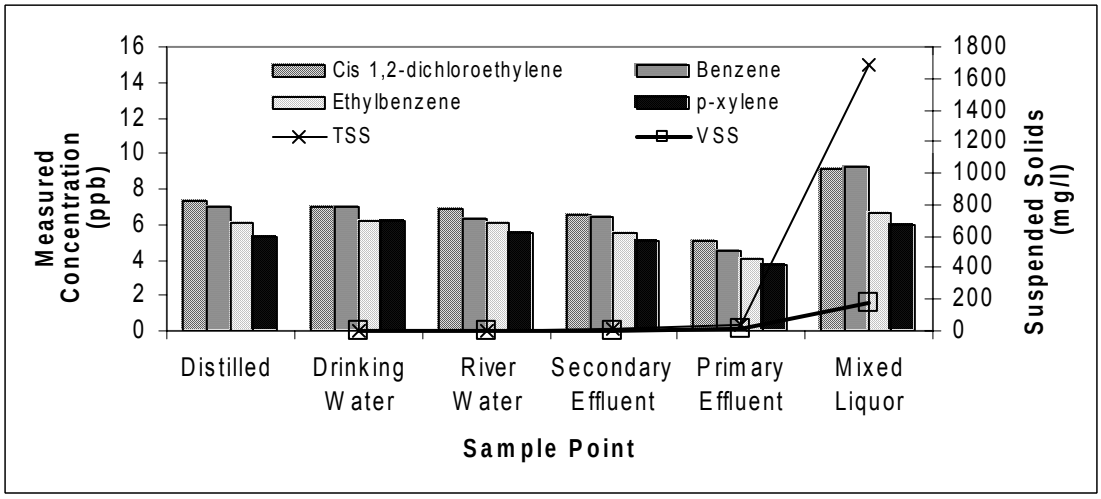


C.

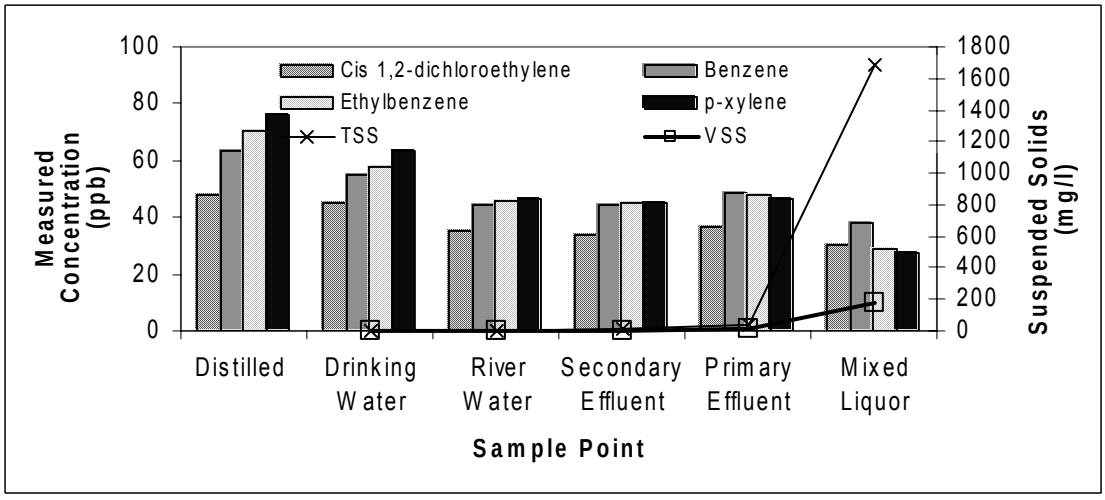
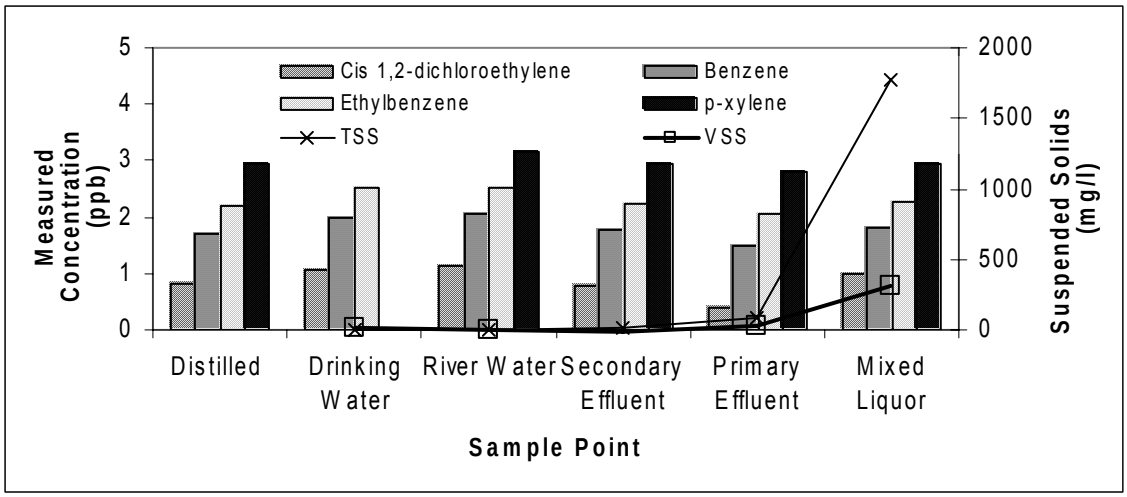
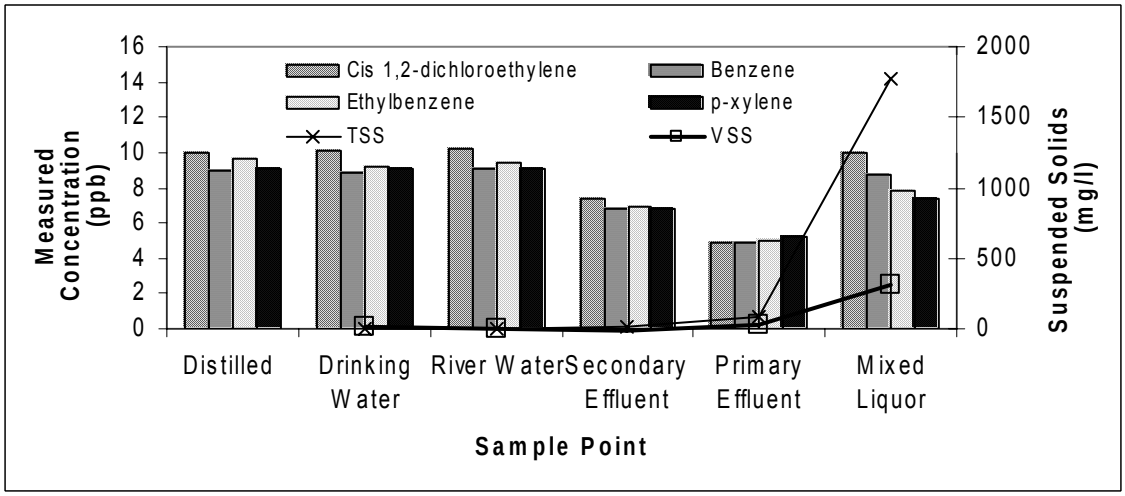


Figure 6.1 Experiment 1 Spiked at A. 1 ppb, B. 10 ppb, and C. 50 ppb

A.



B.



C.

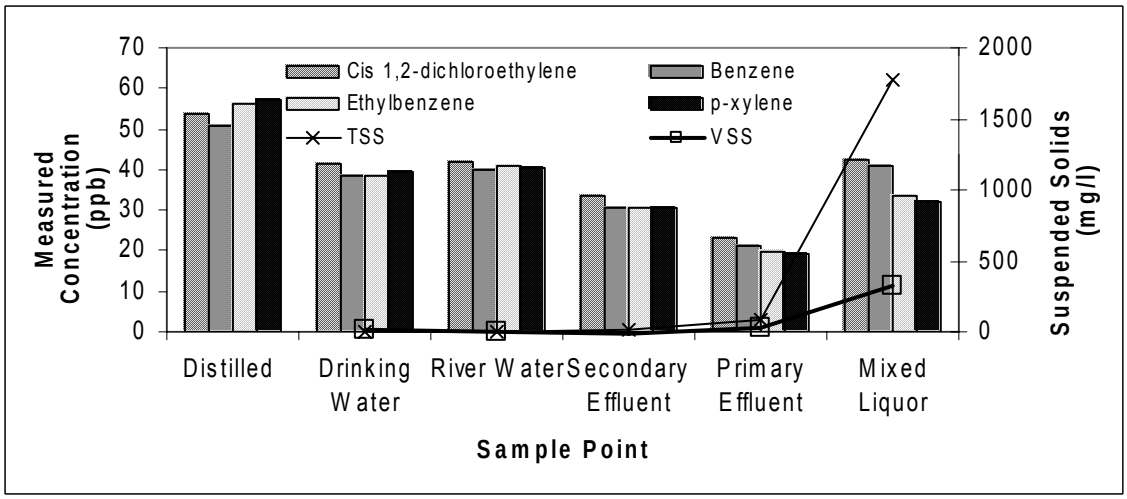


Figure 6.2 Experiment 2 Spiked at A. 1ppb, B. 10 ppb, and C. 50 ppb

Figure 6.2, Figure 6.3, and Figure 6.4 are configured in the same manner as Figure 6.1. Figure 6.2 represents the results from Experiment 2. Figure 6.2 A. depicts the results for the samples spiked at 1 ppb and shows the concentrations increased for each of the VOCs in the order of *cis* 1,2-dichloroethylene, benzene, ethylbenzene, and *p*-xylene. The *cis* 1,2-dichorethylene was the lowest observed concentration at approximately 1 ppb and the *p*-xylene was observed at the greatest concentration of about 3 ppb. The *p*-xylene was not measured for the distilled water sample.

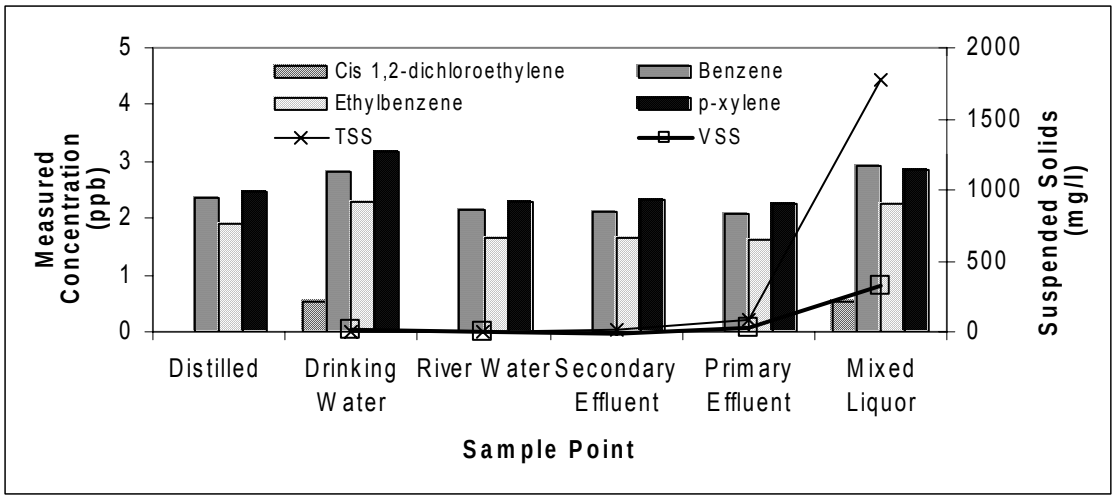
Figure 6.2 B. represents the samples spiked at 10 ppb. Distilled water, drinking water, and river water reported concentrations of about 10 ppb for all four VOCs. The secondary effluent reported concentrations of about 8 ppb while the primary effluent concentrations were around 5 ppb. The mixed liquor reported varying concentrations with the *cis* 1,2-dichloroethylene at 9.95 ppb and the *p*-xylene at 7.37 ppb. Figure 6.2 C. illustrates the results for the samples spiked at 50 ppb. Figure 6.2 C. follows the same trend as figure 6.2 B. except for the distilled water sample reported greater concentrations than any of the other water samples. The primary effluent had the lowest measured concentration for all four VOCs.

Figure 6.3 represents the results for Experiment 3. In this experiment the *cis* 1,2-dichloroethylene was observed in only the water samples of drinking water and mixed liquor, which reported it at less than 1 ppb as seen in Figure 6.3 A. The benzene and *p*-xylene were recovered at similar levels with respect to each other for all six water samples. Ethylbenzene levels were consistently recovered at 0.5 ppb less than *p*-xylene for each water sample. The measured concentration for *p*-xylene in the drinking water and mixed liquor were similar at about 3 ppb. Figure 6.3 B. represents Experiment 3 results for sample spiked at 10 ppb. The distilled water and the mixed liquor yielded similar results. The *cis* 1,2-dichloroethylene and the

benzene were measured at concentrations of 12 ppb in both water samples, while the ethylbenzene and *p*-xylene showed concentrations of 10 ppb for the distilled water and the 8 ppb for the mixed liquor. The drinking water and river water showed similar results all around 10 ppb. The secondary effluent shows concentrations around 7 ppb while the primary effluent depicts concentrations around 5 ppb. Figure 6.3 C. represents the samples spiked at 50 ppb. The distilled water, drinking water, river water, and secondary effluent show concentrations around 45 ppb while the primary effluent reports concentrations around 30 ppb. The *cis* 1,2-dichloroethylene and the benzene report concentrations around 50 ppb for the mixed liquor, while the ethylbenzene and *p*-xylene show concentrations at 30 ppb. In both Figures 6.3 B. and C. the primary effluent is visibly the lowest reported concentration and almost half the known spiked concentration.

Figure 6.4 represents the results for Experiment 4. Figure 6.4 A. is almost identical to Figure 6.3 A. except that the *cis* 1,2-dichloroethylene was not visible in all six water samples for this experiment. The Figure 6.4 B. representing the samples spiked at 10 ppb show similar results for all six water samples. All four VOCs reported concentrations around 5 ppb for all six water samples. Figure 6.4 C. shows *cis* 1,2-dichloroethylene to have the greatest reported concentration in all six water samples followed by benzene and finally ethylbenzene and *p*-xylene with similar concentrations. The primary effluent reported concentrations around 30 ppb. Similar to Figures 6.1 B., Figures 6.2 B. and C., Figure 6.3 B. and C., and Figure 6.4 B. the ethylbenzene and *p*-xylene reported concentrations significantly lower than the *cis* 1,2-dichloroethylene and benzene.

A.



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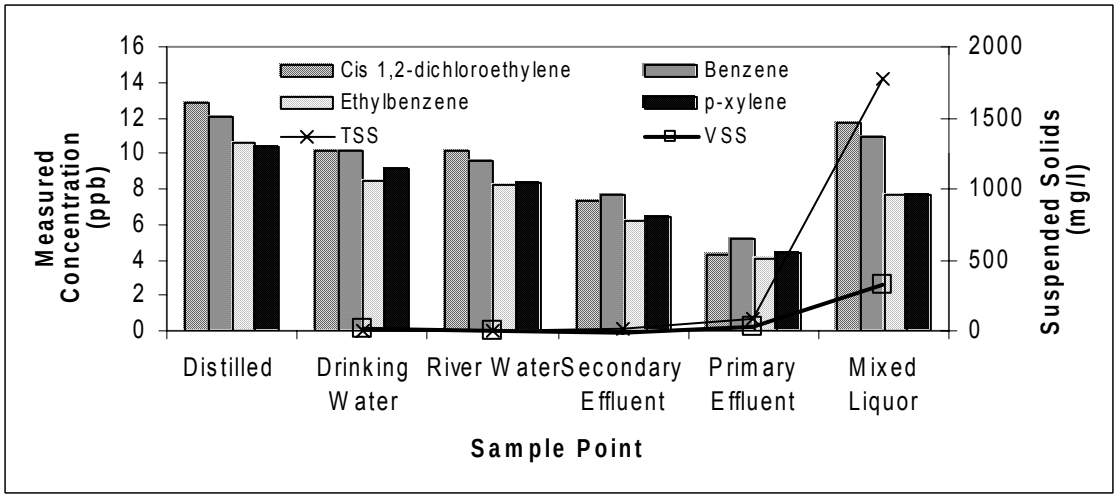


C.

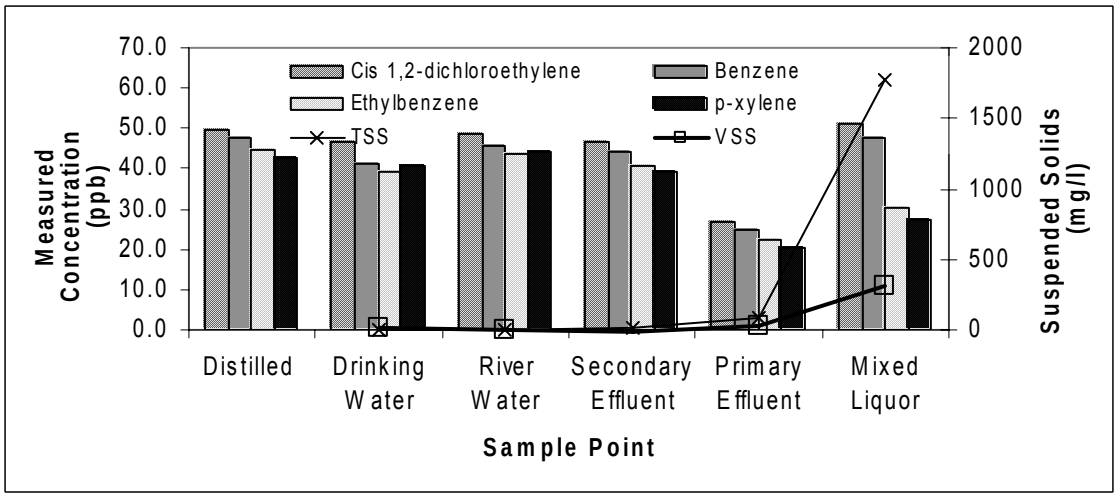
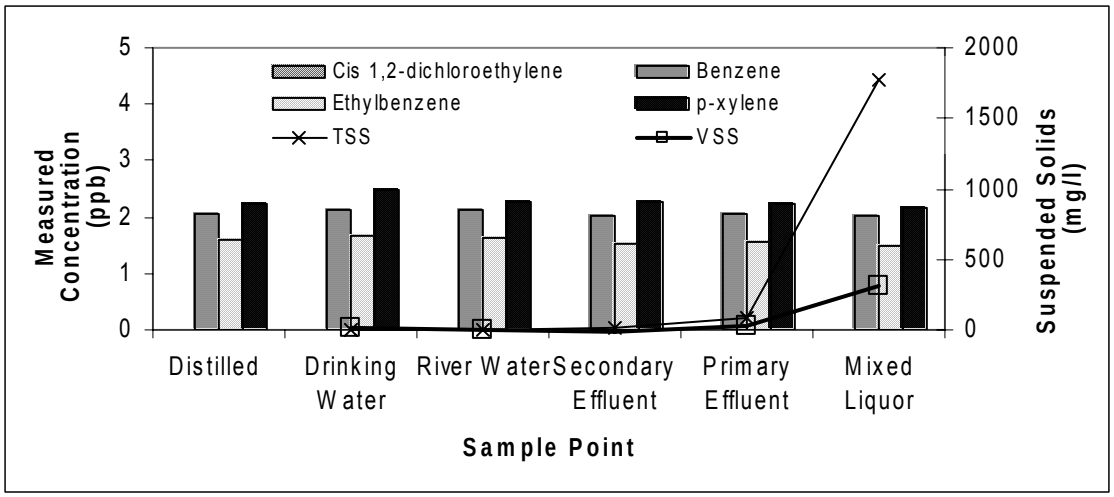
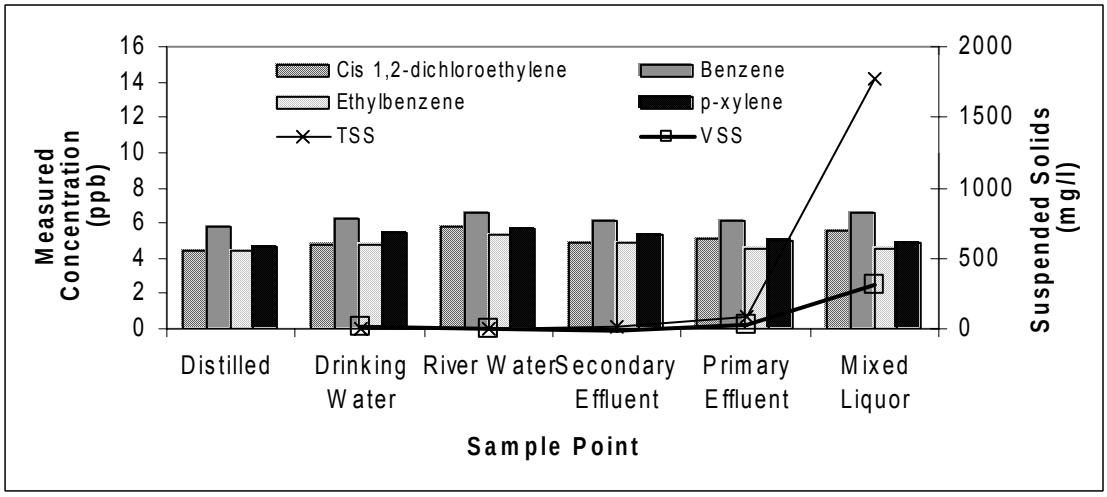


Figure 6.3 Experiment 3 Spiked at A. 1 ppb, B. 10 ppb, and C. 50 ppb

A.



B.



C.

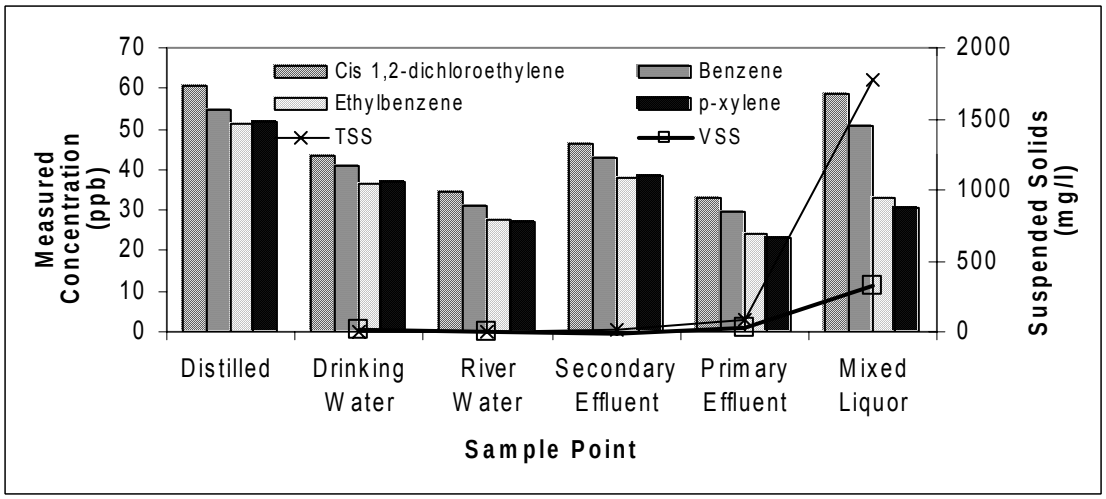


Figure 6.4 Experiment 4 Spiked at A. 1 ppb, B. 10 ppb, and C. 50 ppb

At first it was assumed that the percent VOC recovery would be a function of suspended solids; however excluding Experiment 1 the reported concentration for all four VOCs was approximately half of the known spiked concentration when analyzed in the primary effluent which contained suspended solids, see Figures 6.9. A suspended solids analysis was performed and found that the mixed liquor TSS was two orders of magnitude greater than the TSS in the primary effluent by mass.

The cause for the decrease in measured concentration in the primary effluent maybe caused by absorption to the suspended solids or a reaction with the constituents of the primary effluent. If the VOCs were absorbing onto the suspended solids, similar result would be expected for the mixed liquor samples; however this was not the case. There is the possibility that the VOCs were being retained in the organic material that was suspended in the water samples. It is typical that the primary effluent contained the highest concentration of fatty acids and other organic materials. In the aeration basin, where the mixed liquor was collected, the fatty acids and organic materials from the primary effluent are broken down and are not present to retain the VOCs. The experimental results agree with this hypothesis, since there was a reduction of the VOC concentrations in the primary effluent but not in the mixed liquor.

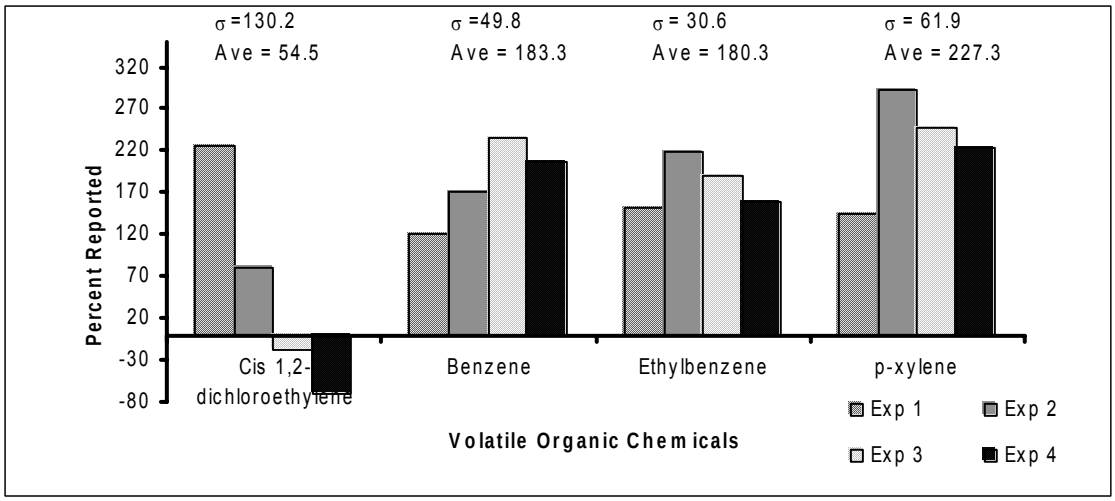
The octanol-water partition coefficient can be used to estimate the ratio of the concentration of VOCs in the octanol phase to the concentration in the aqueous phase. Octanol is an organic solvent used to represent natural organic matter (U.S. Department of Interior, 2005). Table 6.1 lists the octanol-water partition coefficients for the nine VOCs that were analyzed in both rounds 1 and 2. The higher the octanol-water partition coefficient the higher the concentration of the chemical is in the organic phase, therefore an increase in the concentration of a chemical in the organic phase would reduce the concentration of that chemical in the aqueous phase. Table 6.1

shows ethylbenzene and *p*-xylene have octanol-water partition coefficients that are an order of magnitude greater than those of *cis* 1,2-dichloroethylene and benzene. Throughout the first round of experiments, ethylbenzene and *p*-xylene had a lower percent recovery than *cis* 1,2-dichloroethylene and benzene when the mixed liquor from the aeration basin was spiked at 10 ppb and 50 ppb, as seen in Figure 6.10 B and C. The average recovery for *cis* 1,2-dichloroethylene at 10 and 50 ppb in the mixed liquor was 90.8 and 91.2 % respectively and 88.5 and 88.6% for the benzene. The average recovery for ethylbenzene in the mixed liquor when spiked at 10 and 50 ppb was 66.6 and 63.1% respectively and 64.6 and 58.7% for the *p*-xylene.

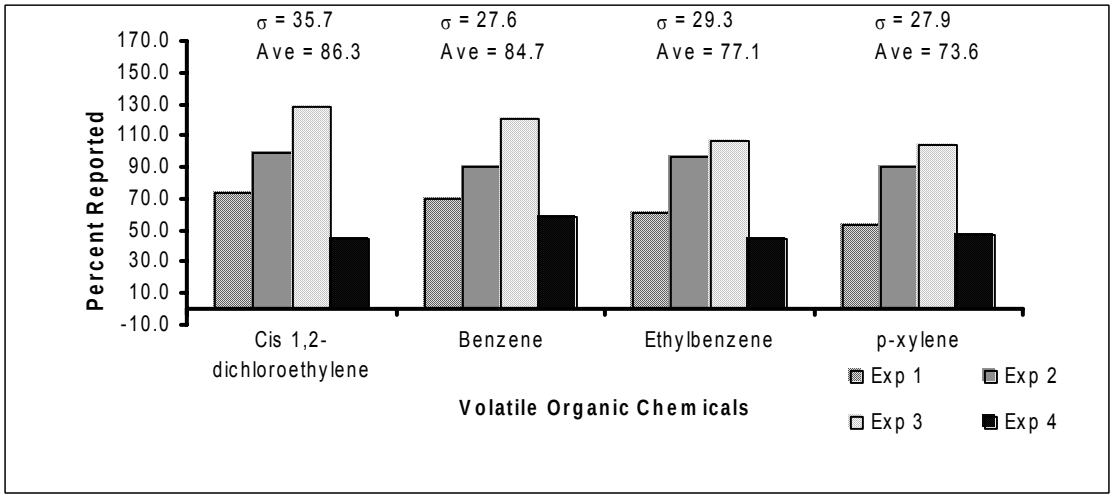
Table 6.1 Octanol-Water Partition Coefficient for tested VOCs

	log Pow
Round 1	
Cis 1,2-dichloroethylene	1.86
Benzene	2.13
Ethylbenzene	3.2
p-xylene	3.15
Round 2	
trans 1,2-dichloroethylene	2.09
styrene	3.2
4 chlorotoluene	3.33
1,3 dichlorobenzene	3.53
o-xylene	3.12
Octanol-Water Partition Coefficents are from the National Institute for Occupational Safety and Health International Chemical Safety Cards	

A.



B.



C.

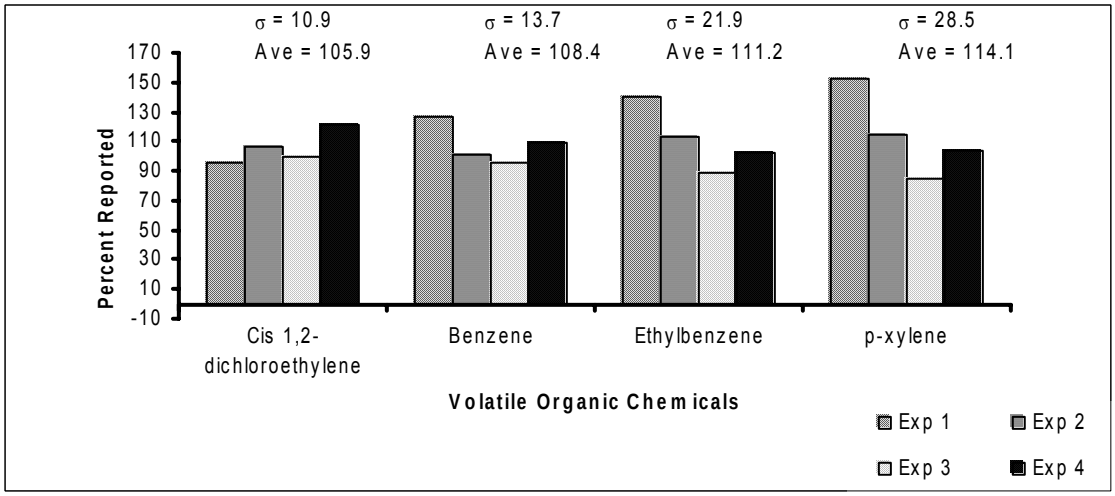
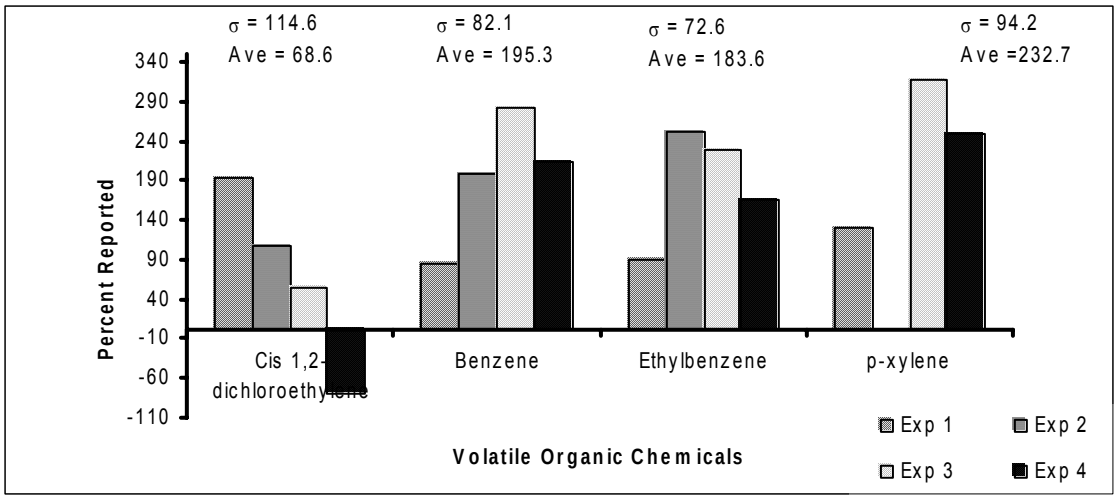


Figure 6.5 Distilled Water Spiked at A. 1 ppb, B. 10 ppb, and C. 50 ppb

Figure 6.5 shows the percent recovery, standard deviation, and average percent recovered of the four VOCs in distilled water for the four experiments when spiked at 1, 10, and 50 ppb. Figure 6.5 A. represents the percent recovery in distilled water for the four experiments when the sample was spiked at 1 ppb. Experiment 1 reported the greatest percent recovery for *cis* 1,2-dicloroethylene at more than 200%, while experiments 3 and 4 had negative percent recoveries. Experiment 3 had the greatest percent recovery for benzene. Experiment 2 had the greatest percent recovery for ethylbenzene and *p*-xylene. Figure 6.5 B. shows Experiment 3 had almost 100% recovery for all four VOCs, while experiment 4 had the least percent recovery for all four VOCs around 50%. Figure 6.5 C. indicates that all four VOCs had near 100 % recovery for all experiments except Experiment 1, which had more than 120% recovery for benzene, ethylbenzene, and *p*-xylene.

Figure 6.6 illustrates the recovery for drinking water in the four experiments. Figure 6.6 is similar to figure 6.5 except Experiment 3 had a positive recovery for *cis* 1,2-dichloroethylene at 1 ppb. Experiment 2 does not show recovery for *p*-xylene at 1 ppb. Figure 6.7 shows the recovery of the four VOCs for river water in all four experiments. Figure 6.7 also follows the same trends observed in figure 6.5 except Experiment 4 shows the lowest percent recovery of the four VOCs when spiked at 50 ppb. Figure 6.8 depicts the recovery seen in the secondary effluent. Figure 6.8 A. and B. follow the same trend as Figure 6.5 A. and B. except at lower recoveries. From Figure 6.8 C. it can be seen that Experiment 2 had the lowest percent recoveries of the four experiments. Figure 6.8 C. also shows that the secondary effluent had near 80 percent recovery for experiments 1, 3, and 4.

A.



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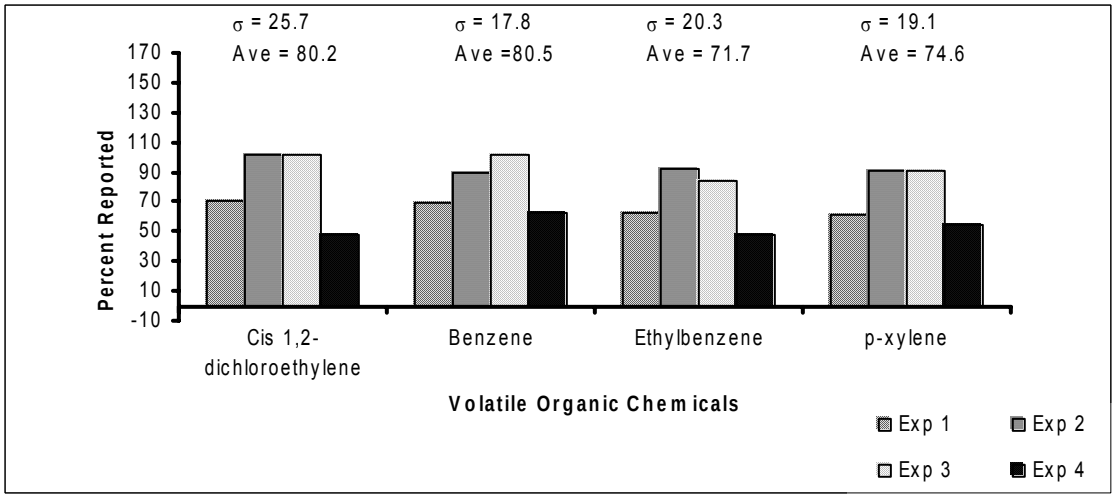


C.

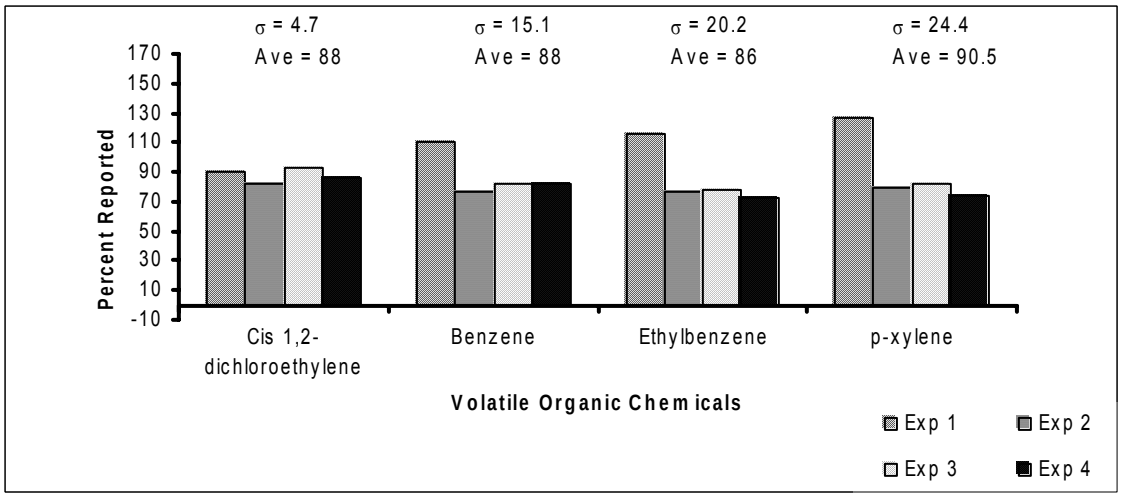
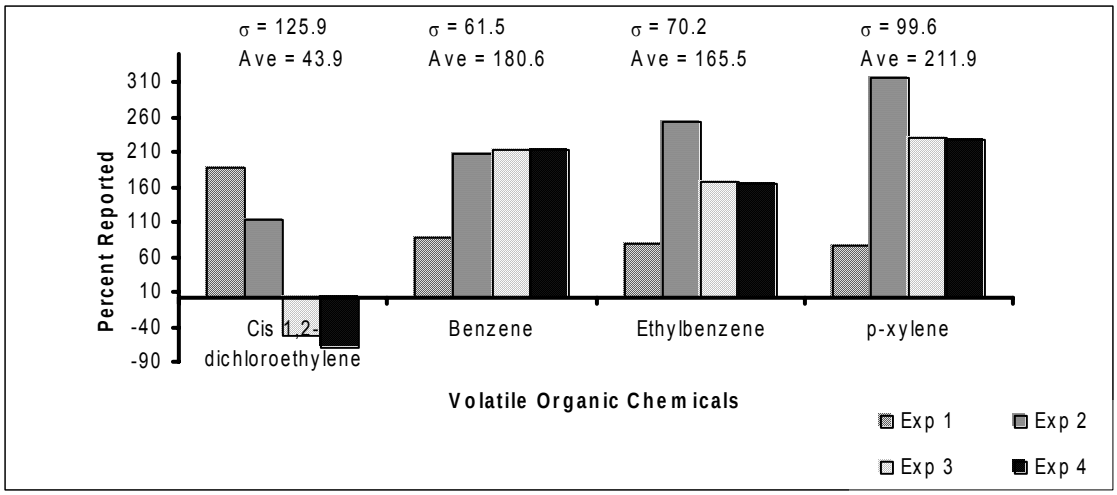


Figure 6.6 Drinking Water Spiked at A. 1 ppb, B. 10 ppb, and C. 50 ppb

A.



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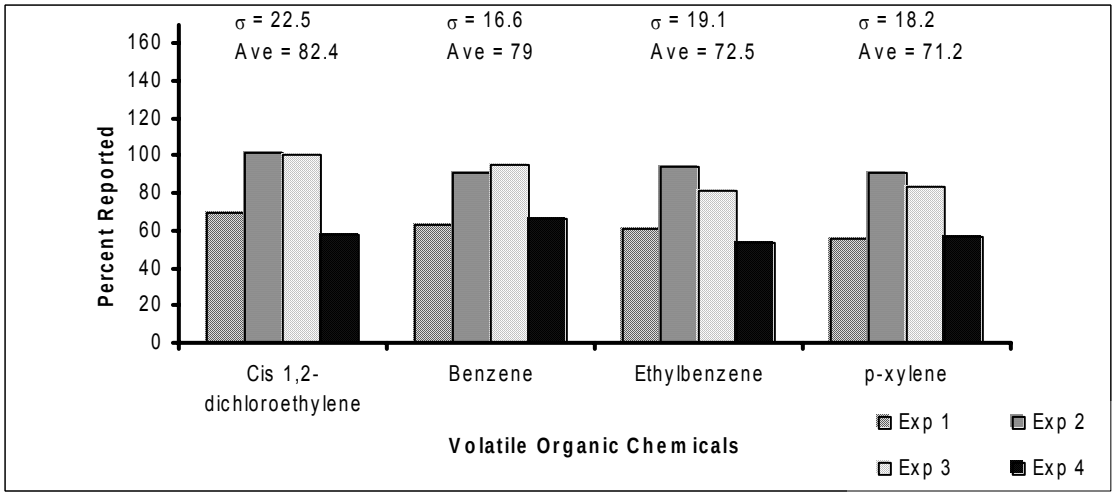

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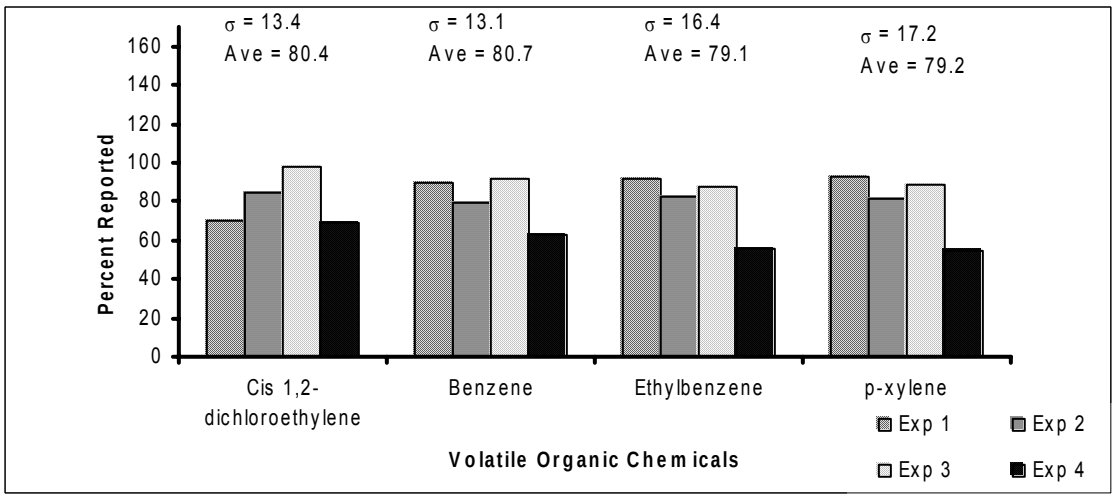
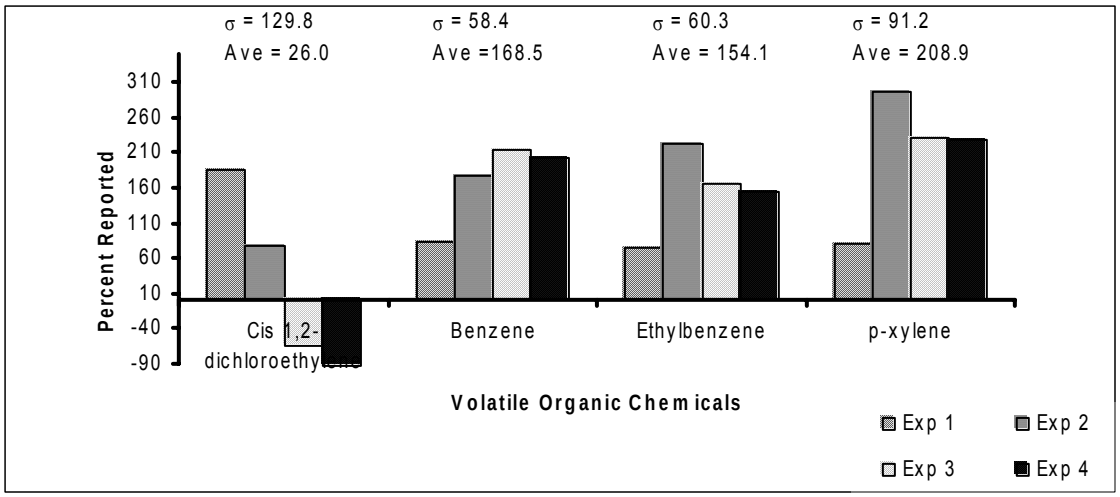
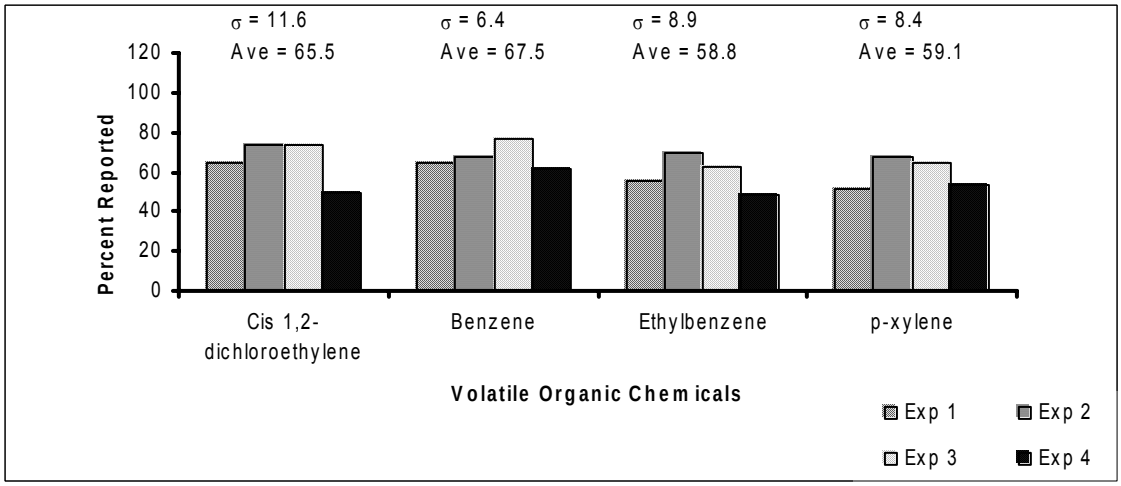


Figure 6.7 River Water Spiked at A. 1 ppb, B. 10 ppb, and C. 50 ppb

A.



B.



C.

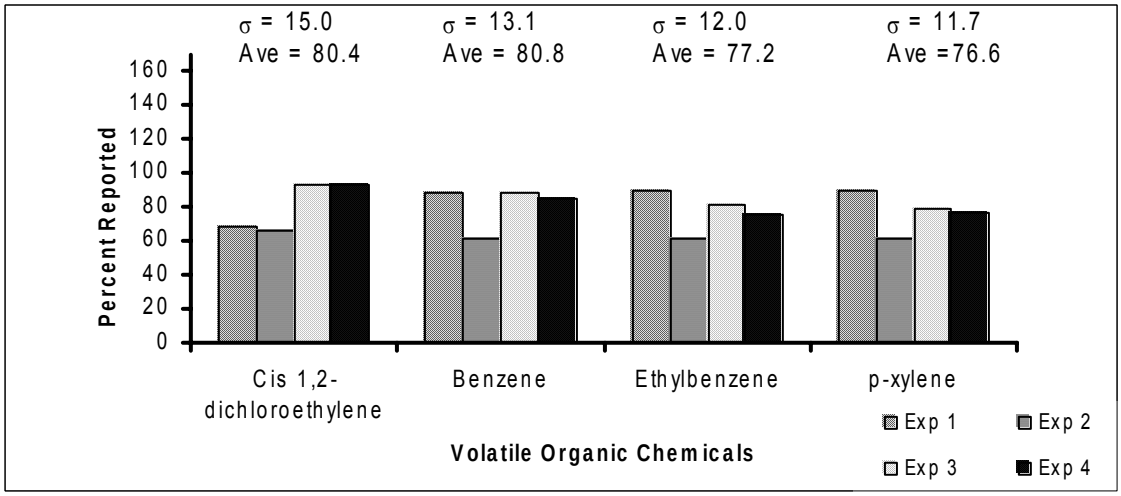
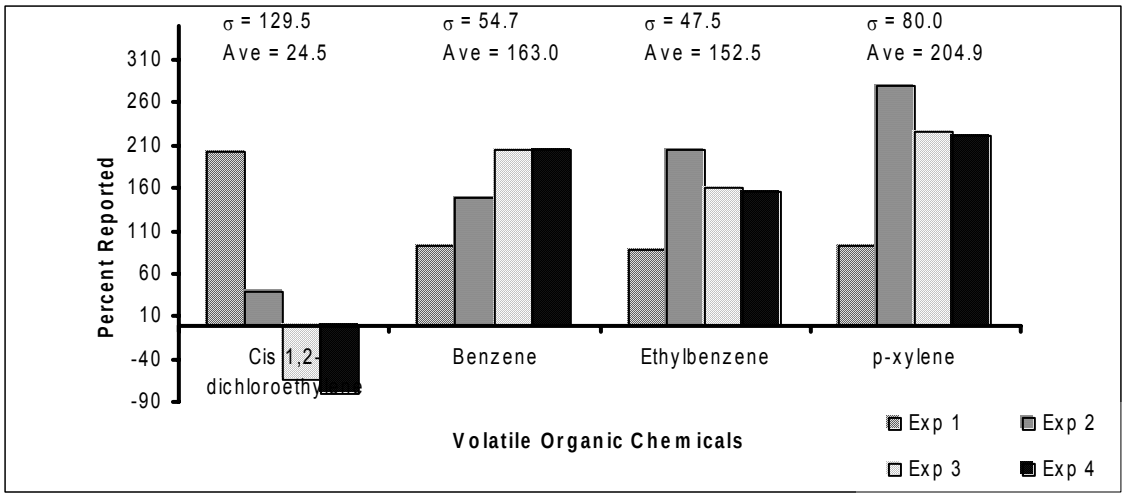
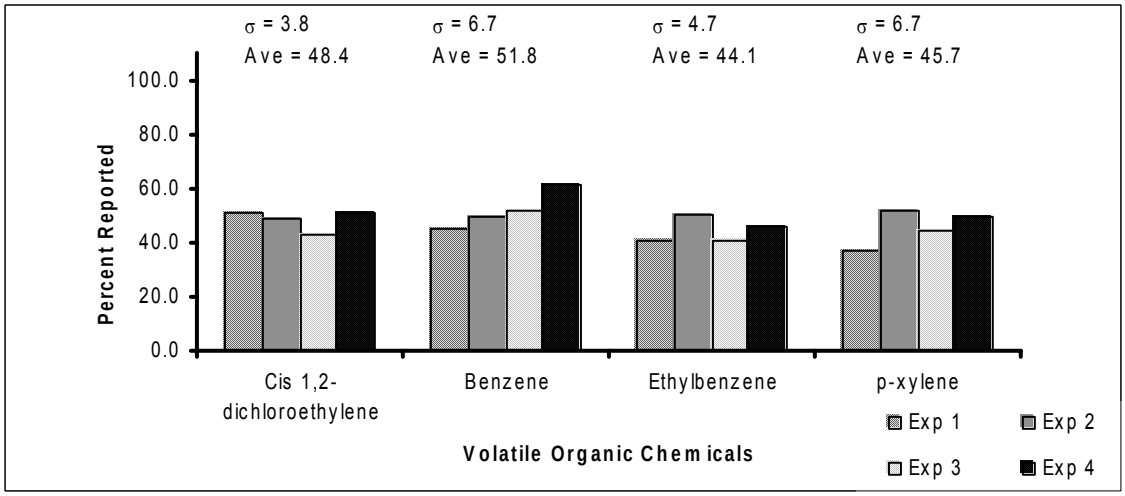


Figure 6.8 Secondary Effluent Spiked at A. 1 ppb, B. 10 ppb, and C. 50 ppb

A.



B.



C.

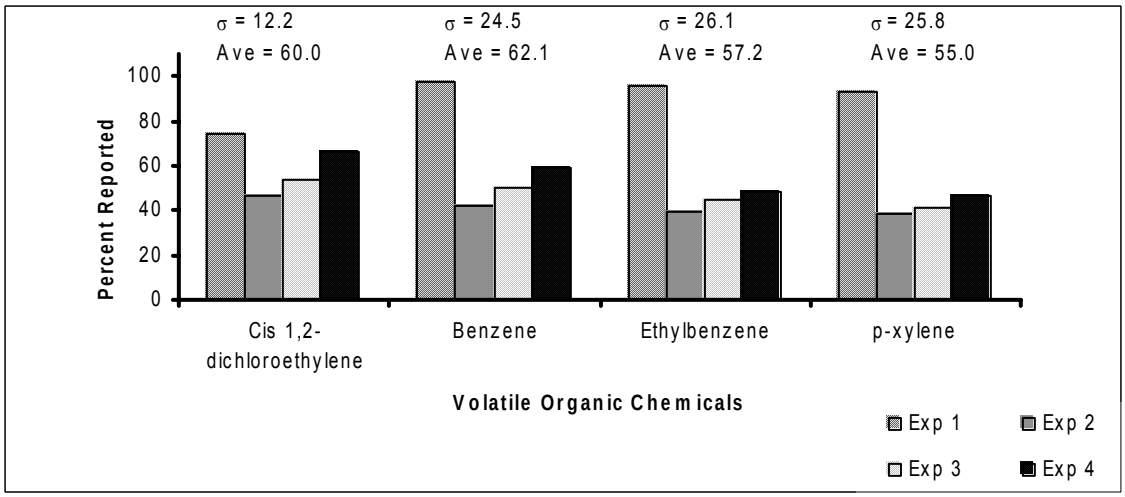


Figure 6.9 Primary Effluent Spiked at A. 1 ppb, B. 10 ppb, and C. 50 ppb

Figure 6.9 represents the recovery of the four VOCs from the primary effluent. Figure 6.9 A. follows the same trend as seen in figure 6.8 A. except the *cis* 1,2-dichloroethylene from Experiment 2 had a percent recovery below 50%. Figure 6.9 A. shows that there was a around a 50% recovery for the four experiments when the primary effluent was spiked at 10 ppb. It can be seen in figure 6.9 C. that the recovery remains around 50% for all the experiments except for Experiment 1.

Figure 6.10 shows the recovery of the four VOCs in the mixed liquor. Figure 6.10 A. and B. follow a very similar trend between experiments to that seen in figure 6.5 A. and B. Figure 6.10 B. shows that there was a much lower in the mixed liquor for ethylbenzene and *p*-xylene than for the *cis* 1,2-dichloroethylene and benzene. The decreased recovery for ethylbenzene and *p*-xylene is even more pronounced in Figure 6.10 C.

Experiment 4 regularly measured a lower recovery for all four VOCs through all six water samples. When only considering samples spiked at 10 and 50 ppb in figures 6.5, 6.6, and 6.7 it can be seen that experiment 4 almost consistently had the lowest percent recovery. Experiment 4 however did have the highest percent recovery for primary effluent spiked at 10 ppb and mixed liquor spiked at 50 ppb, see figures 6.9 B. and 6.10 C. Experiment 4 also had negative percent recovery for *cis* 1,2-dichloroethylen in all water samples when spiked at 1 ppb.

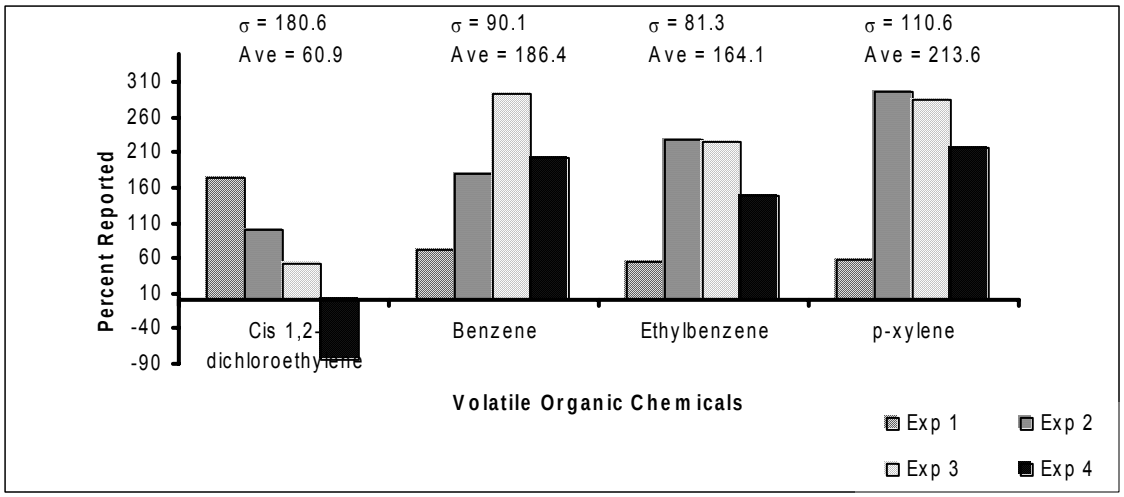
Table 6.2 lists the average reported concentration, the average percent recovery, and their respective standard deviations. These experiments indicate that the Hapsite GC/MS displayed a lack of precision at 1 ppb. The instrument was able to detect all four VOCs in all water samples; however the standard deviation between experiments ranged from 30.8 to 180.6. The standard deviation decreased by an order of magnitude at 10 and 50 ppb when compared to that of 1 ppb. Considering only the samples spiked at either 10 or 50 ppb the percent recovered for Distilled

water, drinking water, and river water ranged from 71.2 to 114.1. The samples spiked at 50 ppb had a higher average percent recovery than did the samples spiked at 10 ppb with one exception. River water spiked at 10 ppb reported an average of 82.4 percent *cis* 1,2-dichloroethylene recovered while the river water spiked at 50 ppb reported 80.4 percent recovered. The secondary effluent reported an average percent recovery range of 59.1 to 65.5 for samples spiked at 10 ppb and a range of 76.6 to 80.8 for those spiked at 50 ppb. The primary effluent samples reported the lowest average percent

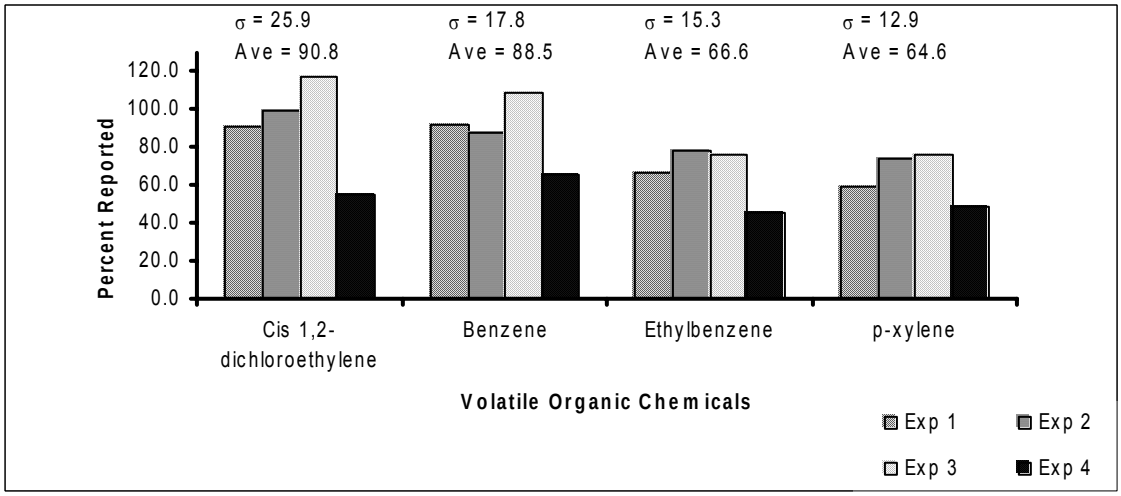
recovery ranging from 44.1 to 51.8 at 10 ppb and 55.0 to 62.1 at 50 ppb. As noted earlier the average percent recovery for the *cis* 1,2-dichloroethylene and the benzene ranged from 88.5 to 91.2 in the samples spiked at 10 and 50 ppb. The range for the ethylbenzene and *p*-xylene was much lower at 58.7 to 66.6.

A comparative analysis was performed using a Hewlett Packard 6890 gas chromatograph with DB-VXR and DB-624 columns in the Pittsburgh Water and Sewer Authorities trace organics lab and the results are listed in Table 6.3. The samples were measured using an OI Analytical 4560 purge and trap sample concentrator fitted with a 25 mL purging vessel and a Supelco VOCARB 3000 trap. In the comparison experiment all six water samples were analyzed with the Cal-1 standard and were spiked at 10 and 50 ppb. When spiked at 50 ppb the primary effluent sample repeatedly extinguished the GC flame ionized detector, therefore this sample was not analyzed. The cause for the inability of the laboratory GC to analyze the primary effluent when spiked at 50 ppb is unknown.

A.



B.



C.

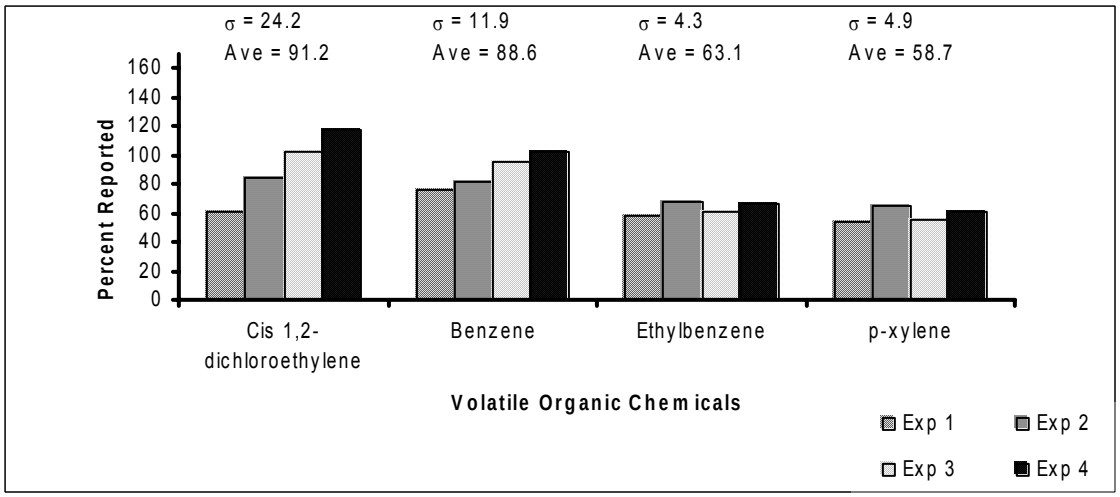


Figure 6.10 Mixed Liquor Spiked at A. 1 ppb, B. 10 ppb, and C. 50 ppb

Table 6.2 Hapsite GC/MS Results

Sample	Reported Concentration								% Recovery							
	Cis-1,2-Dichloroethylene		Benzene		Ethylbenzene		p-Xylene		Cis-1,2-Dichloroethylene		Benzene		Ethylbenzene		p-Xylene	
	Average ppb	Standard Deviation	**Average ppb**	Standard Deviation	**Average ppb**	Standard Deviation	**Average ppb**	Standard Deviation	**Average ppb**	Standard Deviation	**Average ppb**	Standard Deviation	**Average ppb**	Standard Deviation	**Average ppb**	Standard Deviation
Distilled 1ppb	**0.55**	1.30	**1.83**	0.50	**1.80**	0.31	**2.27**	0.62	**54.50**	130.24	**183.25**	49.84	**180.25**	30.58	**227.25**	61.88
Distilled 10ppb	**8.63**	3.57	**8.47**	2.76	**7.71**	2.93	**7.36**	2.79	**86.25**	35.74	**84.68**	27.56	**77.05**	29.28	**73.58**	27.93
Distilled 50ppb	**52.93**	5.47	**54.18**	6.85	**55.60**	10.97	**57.03**	14.26	**105.85**	10.95	**108.35**	13.71	**111.20**	21.93	**114.05**	28.51
Drinking Water 1ppb	**0.69**	1.15	**1.95**	0.82	**1.84**	0.73	**2.33**	0.94	**68.55**	114.60	**195.25**	82.10	**183.63**	72.58	**232.67**	94.20
Drinking Water 10ppb	**8.02**	2.57	**8.05**	1.78	**7.17**	2.03	**7.46**	1.91	**80.15**	25.72	**80.45**	17.77	**71.70**	20.28	**74.60**	19.13
Drinking Water 50ppb	**44.00**	2.33	**43.98**	7.57	**42.98**	10.08	**45.25**	12.20	**88.00**	4.66	**87.95**	15.15	**85.95**	20.17	**90.50**	24.40
River 1ppb	**0.44**	1.26	**1.81**	0.62	**1.66**	0.70	**2.12**	1.00	**43.93**	125.85	**180.60**	61.54	**165.50**	70.24	**211.90**	99.60
River 10ppb	**8.24**	2.25	**7.90**	1.66	**7.25**	1.91	**7.12**	1.82	**82.43**	22.51	**79.00**	16.63	**72.48**	19.10	**71.23**	18.19
River 50ppb	**40.20**	6.72	**40.35**	6.53	**39.55**	8.20	**39.58**	8.58	**80.40**	13.44	**80.70**	13.05	**79.10**	16.39	**79.15**	17.16
Secondary Effluent 1ppb	**0.26**	1.30	**1.69**	0.58	**1.54**	0.60	**2.09**	0.91	**26.03**	129.84	**168.50**	58.40	**154.13**	60.30	**208.88**	91.17
Secondary Effluent 10ppb	**6.55**	1.16	**6.75**	0.64	**5.88**	0.89	**5.91**	0.84	**65.45**	11.60	**67.48**	6.43	**58.80**	8.91	**59.10**	8.37
Secondary Effluent 50ppb	**40.20**	7.51	**40.38**	6.55	**38.58**	6.02	**38.28**	5.85	**80.40**	15.03	**80.75**	13.10	**77.15**	12.05	**76.55**	11.69
Primary Effluent 1ppb	**0.24**	1.29	**1.63**	0.55	**1.53**	0.48	**2.05**	0.80	**24.48**	129.46	**163.00**	54.66	**152.50**	47.50	**204.90**	80.03
Primary Effluent 10ppb	**4.84**	0.38	**5.18**	0.67	**4.41**	0.47	**4.57**	0.67	**48.38**	3.80	**51.75**	6.73	**44.08**	4.69	**45.65**	6.66
Primary Effluent 50ppb	**30.00**	6.09	**31.03**	12.23	**28.58**	13.07	**27.48**	12.92	**60.00**	12.18	**62.05**	24.47	**57.15**	26.15	**54.95**	25.84
Mixed Liquor 1ppb	**0.61**	1.09	**1.86**	0.90	**1.64**	0.81	**2.14**	1.11	**60.85**	108.61	**186.43**	90.06	**164.13**	81.33	**213.55**	110.57
Mixed Liquor 10ppb	**9.08**	2.59	**8.85**	1.78	**6.66**	1.53	**6.46**	1.29	**90.80**	25.92	**88.50**	17.82	**66.60**	15.30	**64.63**	12.91
Mixed Liquor 50ppb	**45.60**	12.09	**44.28**	5.97	**31.55**	2.16	**29.33**	2.44	**91.20**	24.18	**88.55**	11.94	**63.10**	4.33	**58.65**	4.88

Note: Averages are the result of 4 measurements

The resultant concentrations acquired using the Hewlett Packard 6890 GC are listed in table 6.3 as well as the percent recovery of the known spiked concentration. The distilled water sample spiked at 10 ppb had recovery ranging from 103.7% for *p*-xylene to 105.9 for *cis* 1,2-dichloroethylene. When spiked at 50 ppb the range was 101.1% to 103.5%. The river water when spiked at 10 ppb had a recovery range of 100.7% to 101.0% and a range of 96.5% to 100.7% when the sample was spiked at 50 ppb. Drinking water ranged from 97.1% to 106.8% at 10 ppb and 99.6% to 108.0% at 50 ppb. The secondary effluent when spiked at 10 and 50 ppb had a percent recovery ranging from 100.4% to 108.4% and 97.2% to 107.5% respectively. The primary effluent had a recovery range of 99.0% to 114.9% when spiked at 10 ppb. The mixed liquor sample had a percent recovery range of 67.9% to 74.1% when spiked at 10 ppb and 65.0% to 74.5% when spiked at 50 ppb.

The Pittsburgh Water and Sewer Authority's trace organics lab recognizes a percent recovery of 100 ± 20% as accurate. The distilled water, river water, drinking water, secondary effluent, and the primary effluent spiked at 10 ppb were within the acceptable range when analyzed with the PWSA gas chromatograph. When only considering the samples spiked at 10 and 50 ppb and analyzed using the Hapsite GC/MS, the *distilled* water and drinking water samples spiked at 50 ppb were the only two water matrix that reported a percent recovery that was between 80% and 120% for all four chemicals that were tested. Using the Hapsite GC/MS, the distilled water, drinking water, and mixed liquor spiked at 10 ppb reported acceptable percent recoveries for the *cis* 1,2-dichloroethylene and benzene. The river water when spiked at 10 ppb had a recovery of 82.4% for the *cis* 1,2-dichloroethylene which was acceptable and 79.0% for the benzene which is just below the acceptable range. The river water and mixed liquor when spiked at 50 ppb reported acceptable percent recovery ranges for the *cis* 1,2-dichloroethylene and benzene. These

lower but still acceptable percent recoveries suggested that the Hapsite GC/MS is less sensitive then the laboratory GC used by PWSA.

The significant difference seen in this comparison is that the primary effluent reported near 100% recovery on the PWSA GC and almost 50% and 60% recovery when analyzed with the Hapsite GC/MS. Also the mixed liquor had a percent recovery with the Hapsite GC/MS near 90% for the *cis* 1,2-dichloroethylene and benzene when spiked at 10 and 50 ppb and a recovery around 70% for all four chemicals when analyzed with the laboratory GC.

Table 6.3 Pittsburgh Water and Sewer Authority Gas Chromatograph Results

	Reported Concentration				% Recovery			
Sample ID:	Cis-1,2-Dichloroethylene	Benzene	Ethylbenzene	p-Xylene	Cis-1,2-Dichloroethylene	Benzene	Ethylbenzene	p-Xylene
Distilled 10ppb	10.59	10.54	10.41	10.37	105.94	105.43	104.13	103.72
Distilled 50ppb	51.15	50.56	51.74	51.33	102.30	101.12	103.48	102.65
River 10ppb	10.08	10.10	10.07	10.10	100.79	100.96	100.66	100.98
River 50ppb	50.10	48.28	50.35	50.11	100.20	96.55	100.70	100.22
Drinking Water 10ppb	10.25	9.71	10.68	10.64	102.52	97.13	106.76	106.41
Drinking Water 50ppb	52.20	49.78	54.02	53.32	104.39	99.55	108.04	106.64
Secondary Effluent 10ppb	10.51	10.04	10.84	10.71	105.06	100.36	108.38	107.11
Secondary Effluent 50ppb	50.93	48.59	53.74	51.15	101.86	97.17	107.49	102.31
Primary Effluent 10ppb	10.86	9.90	11.49	11.38	108.55	98.96	114.87	113.77
Mixed Liquor 10ppb	7.14	6.79	7.41	7.16	71.39	67.92	74.13	71.57
Mixed Liquor 50ppb	36.66	32.50	37.26	33.97	73.33	65.01	74.52	67.94

A second round of experiments was performed using five addition chemicals. The five VOCs used were *trans* 1,2-dichloroethylene, styrene, 4-chlorotoluene, 1,3-dichlorobenzene, and o-xylene. Four experimental runs were performed with these chemicals, but unlike the results from the first round there was no uniformity. The instrument was routinely unable to detect *trans* 1,2-dichloroethylene. The instrument during initial setup had been able to detect the *trans* 1,2-dichloroethylen. During this initial stage when the *trans* 1,2-dichloroethylene had been detected by the instrument, it had been in a standard with only ethylbenzene and *o*-xylene. The *trans* 1,2-dichloroethylene has a higher vapor pressure than most of the other chemicals in the Cal-2 standard so it could possibly be volatilizing into the atmosphere before the probe was inserted into the water sample (International, 2005). This possibility is unlikely though since the *cis* 1,2-dichloroethylene used in the first round of experiments, which has a similar vapor pressure, reported similar results to the other chemical used in that round. It is unclear exactly why the instrument was unable to detect the *trans* 1,2-dichloroethylene regularly. Most samples spiked at 30 ppb reported concentrations of approximately half for all contaminants.

The exact cause for the poor results from the second round of experiments is not known. The Hapsite GC/MS used in this research was the property of the Ohio River Valley Water Sanitation Commission and was on loan to PWSA for a short period of time. The second round was performed in a considerably shorter time period than that of the first round of experiments, because the instrument had to be returned, not allowing for fine tuning the instrument to optimize the analysis program for the tested chemicals. The first round of experiments had approximately two months in which the instruments analysis program was adjusted to optimize the settings for the specific VOCs. The second round was performed in approximately three weeks not allowing for any extra time for similar adjustments to things such as the temperature program and run

time. During the forth and final experiment for the second round the internal standard gas canister was running low and the instrument warned that it must be changed. The warning was over ruled and the analysis continued.

A temperature effect was noticed while using the instrument. The water sample temperature affected the reported results. It is logical that since the instrument takes a sample by bubbling nitrogen through the water sample to cause the VOCs to volatilize out of solution that the water temperature would effect the amount of VOCs that volatilize. If the water sample was at a lower temperature than that of what was used to calibrate the instrument then the instrument reported a false low concentration. In order to determine the degree of the temperature effect four distilled water samples were spiked with the Cal-1 standard at 30 ppb and analyzed at 10, 15, 20, and 25 ^{o}C. The results can be seen in Figure 6.11. When analyzed at 10 ^{o}C the reported concentration was approximately 15 ppb, or 50% of the spiked concentration, for all four VOCs. When the temperature was increased to 25 ^{o}C the percent recovered was approximately 83%.

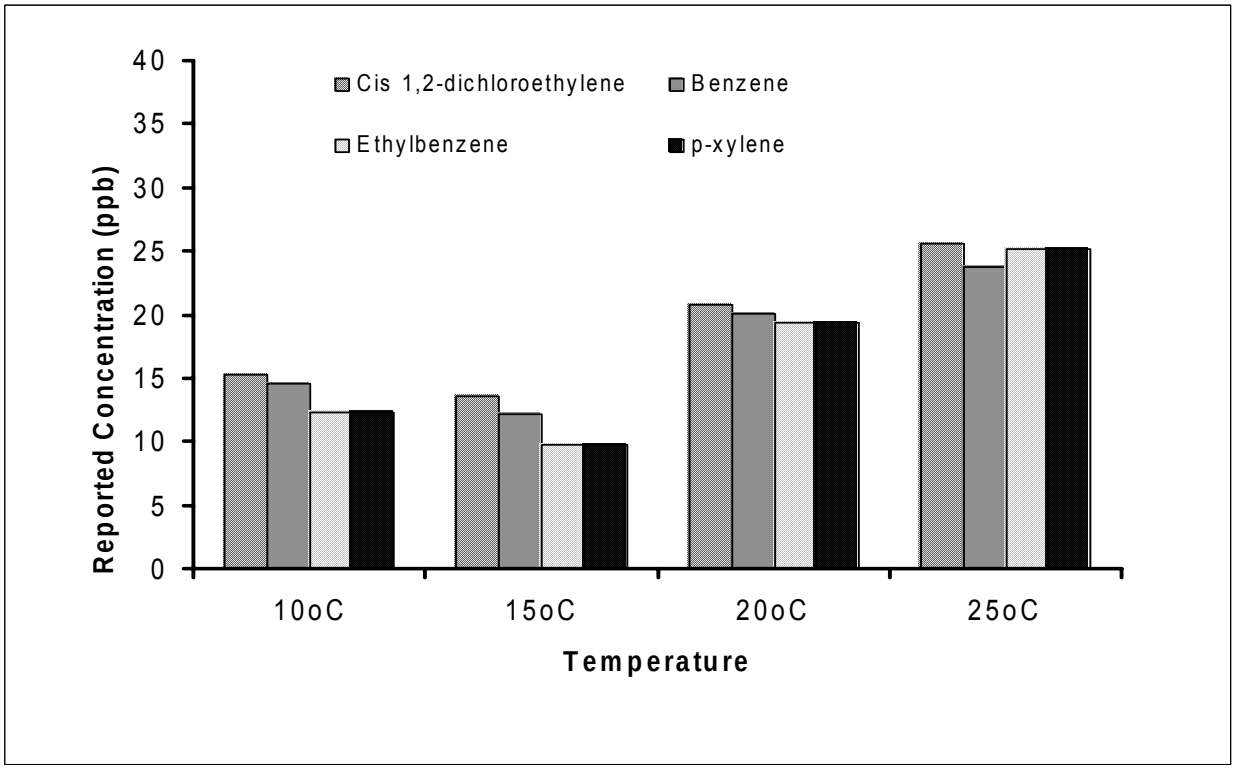


Figure 6.11 Temperature effect on reported concentration

7.0 SUMMARY AND CONCLUSIONS

Though it does not seem likely, that a wastewater collection system and treatment plant would be the target of a terrorist attack, it is still an important issue that must be considered. There is not only the threat of a possible attack directly on a treatment system there is the added possibility of secondary contamination. All steps taken to protect against and recover from a contamination incident within a treatment system would also help safeguard and recover from an accidental spill. The framework that has been developed in this research can help wastewater treatment plant personnel decide if there is a threat, what are the vulnerabilities of the facility to that threat, and help determine appropriate actions to be taken. The research performed has also identified an instrument that could be used for detection of a large number of volatile organic compounds in several different water matrix, including primary and secondary effluents and mixed liquor from the aeration basin.

The primary objectives of this research were:

- Develop a contaminant universe for wastewater collection and treatment systems.
- Develop and validate a prioritization frame work for identifying agents of concern for use in this project and USEPA; and
- Determine current detection capabilities for VOC contamination in wastewater collection and treatment systems using the Hapsite portable GC/MS.

The following are observation for the Prioritization Framework:

- The basic foundation for a framework has been developed that can be used to determine what contaminants are a threat to a wastewater collection and treatment system.
- The framework was successful in scoring and ranking the first fifteen contaminants that were evaluated.
- Scoring tables need to be developed for criteria other than potency
- Research needs to be performed to determine the fate and transport of uncommon contaminants through the collection system and treatment process including radiological contaminants.

The following are conclusions for the Detection of VOCs using the Hapsite GC/MS:

- The Hapsite was capable of detecting most of the evaluated VOCs at a minimum concentration of 1 ppb in all six water matrix.
- There is a significant effect on the results caused by water sample temperatures that vary from the temperatures used during the calibration of the instrument.
- The instrument will report a false value of low concentration when being used to analysis VOCs in the primary effluent.
- There may be a reported false value of low concentration in the mixed liquor from the aeration basin depending on depending on the VOC's octanol-water partition coefficient
- The instrument is capable of being used for the initial analysis of wastewater and can be used to determine if further laboratory testing is needed.

APPENDIX

SUPPLEMENTAL MATERIAL

Table 8.1 Ammonia Worker/Public Health

Criterion	Worker/Public Health		
	Weighting Factor	Score	Comments
Availability	0.18	5	[AM01]Ammonia occurs naturally and is produced by human activity. It is applied directly into soil on farm fields, and is used to make fertilizers for farm crops, lawns, and plants. Many household and industrial cleaners contain ammonia. It is also used for medical applications (e.g., smelling salts).
Potency	0.16	2	[AM01]OSHA has set the eight-hour exposure limit at 25 ppm in air. The short-term (15 minutes) exposure level is set at 35 ppm. [AM02]NIOSH has recommended 50 ppm as a ceiling determined by a 5-minute sampling period. [AM04]The 96 hour LC_{50} for fish can range from 0.21 to 8.2 mg/l depending
Persistence	0.04	3	[AM01]**Ammonia does not last long in the environment?.** It is rapidly taken up by plants, bacteria, and animals. Ammonia gas can be dissolved in water. When exposed to open air, it quickly turns into a gas. [AM04]Solubility in water is 0.54g/ml at 20°C The vapour pressure at 26°C is 1013 kPa [AM05]Since nitrifying bacteria grow more slowly that carbonaceous bacteria, the BOD curve for ammonia begins several days after the carbonaceous BOD. Bacteria can readily convert ammonia to
Introduction/Dispersion	0.04	5	No special equipment is needed to introduce ammonia into wastewater collection and treatment systems.
Process Removal	0.02	2	[AM02]Ammonia is incompatible with strong oxidizers (e.g., calcium, hypochlorite bleaches, gold, mercury, silver, halogens). [AM01]Ammonia does not last long in the environment. It is rapidly taken up by plants, bacteria, and animals. Ammonia gas can be dissolved in water. When exposed to open air, it quickly turns into a gas. [AM03]The four historically used treatment processes for ammonia removal are: biological nitrification, breakpoint chlorination, air stripping (pH adjustment), and selective ion exchange. Biological nitrification is most common.
Storability	0.04	4	[AM02]Outside or detached storage is preferred. Inside, it should be stored in cool, well-ventilated, noncombustible location. Should be kept away from sources of ignition and other chemicals.
Outcomes	0.28	2	[AM02]Inhalation exposures of 500 ppm for 30 minutes have caused upper respiratory irritation, tearing, increased pulse rate and blood pressure. Death has been reported after an inhalation exposure to 10,000 ppm for an unknown duration. Dermal exposure to solutions of 2% ammonia can cause burns and blisters after 15 minutes of exposure.
Public Perception	0.24	2	The public uses ammonia as a cleaner and for other household and industrial purposes.
Composite Score		**2.8**	

References/Comments:

[AM01] http://www.atsdr.cdc.gov/tfacts126.html

[AM02] Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

[AM03] http://pretreater.ensafe.com/content/v01n04/ammonia_wastewater_basics.asp

[AM04] http://www.cdc.gov/niosh/ipcsneng/neng0414.html

[AM05] Verschueren, Karel. Handbook of Environmental Data on Organic Chemicals, 4th Edition. 2001.

Table 8.2 Ammonia Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	5	[AM01]Ammonia occurs naturally and is produced by human activity. It is applied directly into soil on farm fields, and is used to make fertilizers for farm crops, lawns, and plants. Many household and industrial cleaners contain it. It is also used in smelling salts.
Potency	0.11	1	Ammonia can be metabolized by the appropriate unit processes.
Persistence	0.10	3	[AM01]Ammonia does not last long in the environment. It is rapidly taken up by plants, bacteria, and animals. Ammonia gas can be dissolved in water. When exposed to open air, it quickly turns into a gas. [AM04]Solubility in water is 0.54g/ml at 20°C The vapour pressure at 26°C is 1013 kPa [AM05]The BOD curve for ammonia begins after several days. At this time bacteria will convert it to nitrates
Introduction/Dispersion	0.11	5	No special equipment is needed to introduce ammonia into wastewater collection and treatment systems.
Process Removal	0.09	2	[AM02]It is incompatible with strong oxidizers, calcium, hypochlorite bleaches, gold, mercury, silver, halogens. [AM01]Ammonia does not last long in the environment. It is rapidly taken up by plants, bacteria, and animals. Ammonia gas can be dissolved in water. When exposed to open air, it quickly turns into a gas. [AM03]The four historically used treatment processes for ammonia removal are: biological nitrification, breakpoint chlorination, air stripping (pH adjustment), and selective ion exchange. Biological nitrification is most common.
Storability	0.07	2	[AM02]Outside or detached storage is preferred. Inside, it should be stored in cool, well-ventilated, noncombustible location. Should be kept away from sources of ignition and other chemicals.
Outcomes	0.26	1	Ammonia can be metabolized by the appropriate unit processes.
Public Perception	0.02	2	The public uses ammonia as a cleaner and for other household and industrial purposes.
Composite Score		**2.8**	

References/Comments:

AM01 http://www.atsdr.cdc.gov/tfacts126.html

AM02 Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

AM03 http://pretreater.ensafe.com/content/v01n04/ammonia_wastewater_basics.asp

AM04 http://www.cdc.gov/niosh/ipcsneng/neng0414.html

Table 8.3 Ammonia Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	5	[AM01]Ammonia occurs naturally and is produced by human activity. It is applied directly into soil on farm fields, and is used to make fertilizers for farm crops, lawns, and plants. Many household and industrial cleaners contain it. It is also used in smelling salts.
Potency	0.06	1	Ammonia will have little ability to damage or destroy the wastewater collection and treatment system. The lower explosive limit (LEL) is 15%. The upper explosive limit (UEL) is 28%.
Persistence	0.05	3	[AM01]Ammonia does not last long in the environment. It is rapidly taken up by plants, bacteria, and animals. Ammonia gas can be dissolved in water. When exposed to open air, it quickly turns into a gas. [AM04]Solubility in water is 0.54g/ml at 20°C The vapour pressure at 26°C is 1013 kPa [AM05]The BOD curve for ammonia begins after several days. At this time bacteria will convert it to nitrates
Introduction/Dispersion	0.06	5	No special equipment is needed to introduce ammonia into wastewater collection and treatment systems.
Process Removal	0.04	2	[AM02]It is incompatible with strong oxidizers, calcium, hypochlorite bleaches, gold, mercury, silver, halogens. [AM01]Ammonia does not last long in the environment. It is rapidly taken up by plants, bacteria, and animals. Ammonia gas can be dissolved in water. When exposed to open air, it quickly turns into a gas. [AM03]The four historically used treatment processes for ammonia removal are: biological nitrification, breakpoint chlorination, air stripping (pH adjustment), and selective ion exchange. Biological nitrification is most common.
Storability	0.02	4	[AM02]Outside or detached storage is preferred. Inside, it should be stored in cool, well-ventilated, noncombustible location. Should be kept away from sources of ignition and other chemicals.
Outcomes	0.32	2	Minimal damage or little or no destruction is expected from introduction of ammonia into the wastewater collection system.
Public Perception	0.29	2	The public uses ammonia as a cleaner and for other household and industrial purposes.
Composite Score		**2.7**	

References/Comments:

[AM01] http://www.atsdr.cdc.gov/tfacts126.html

[AM02] Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

[AM03] http://pretreater.ensafe.com/content/v01n04/ammonia_wastewater_basics.asp

[AM04] http://www.cdc.gov/niosh/ipcsneng/neng0414.html

LEL = Lower Explosive Limit. The percentage of vapor in the air below which a fire can't occur because there isn't enough fuel: the mixture is said to be too lean.

UEL = Upper Explosive Limit. The percentage of vapor in the air above which there isn't enough air for a fire: the mixture is said to be too rich.

Table 8.4 Ammonia Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	5	[AM01]Ammonia occurs naturally and is produced by human activity. It is applied directly into soil on farm fields, and is used to make fertilizers for farm crops, lawns, and plants. Many household and industrial cleaners contain it. It is also used in smelling salts.
Potency	0.06	1	If not removed by the treatment processes, ammonia will be easily removed or metabolized in the environment.
Persistence	0.16	3	[AM01]Ammonia does not last long in the environment. It is rapidly taken up by plants, bacteria, and animals. Ammonia gas can be dissolved in water. When exposed to open air, it quickly turns into a gas. [AM04]Solubility in water is 0.54g/ml at 20°C The vapor pressure at 26°C is 1013 kPa [AM05]The BOD curve for ammonia begins after several days. At this time bacteria will convert it to nitrates
Introduction/Dispersion	0.03	5	No special equipment is needed to introduce ammonia into wastewater collection and treatment systems.
Process Removal	0.16	2	[AM02]It is incompatible with strong oxidizers, calcium, hypochlorite bleaches, gold, mercury, silver, halogens. [AM01]Ammonia does not last long in the environment. It is rapidly taken up by plants, bacteria, and animals. Ammonia gas can be dissolved in water. When exposed to open air, it quickly turns into a gas. [AM03]The four historically used treatment processes for ammonia removal are: biological nitrification, breakpoint chlorination, air stripping (pH adjustment), and selective ion exchange. Biological nitrification is most common.
Storability	0.03	2	[AM02]Outside or detached storage is preferred. Inside, it should be stored in cool, well-ventilated, noncombustible location. Should be kept away from sources of ignition and other chemicals.
Outcomes	0.20	1	[AM01]Ammonia does not last long in the environment. It is rapidly taken up by plants, bacteria, and animals. Ammonia gas can be dissolved in water. When exposed to open air, it quickly turns into a gas. [AM04]Solubility in water is 0.54g/ml at 20°C The vapour pressure at 26°C is 1013 kPa [AM05]The BOD curve for ammonia begins after several days. At this time bacteria will convert it to nitrates
Public Perception	0.33	2	The public uses ammonia as a cleaner and for other household and industrial purposes.
Composite Score		**2.1**	

References/Comments:

[AM01] http://www.atsdr.cdc.gov/tfacts126.html

[AM02] Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

[AM03] http://pretreater.ensafe.com/content/v01n04/ammonia_wastewater_basics.asp

[AM04] http://www.cdc.gov/niosh/ipcsneng/neng0414.html

Table 8.5 Arsenic Worker/Public Health

Criterion	Worker/Public Health		
	Weighting Factor	Score	Comments
Availability	0.18	5	[AR01]Arsenic is used as a pesticide, herbicide, larvacide, and insecticide. Arsenic is used to preserve wood and used in many industrial processes.
Potency	0.16	4	[AR02] OSHA PEL is 10 $\mu g/m^3$ of air for an 8 hour work day.
Persistence	0.04	4	[AR02]Arsenic cannot be destroyed in the environment it can only change its form. [AR03]Arsenic is insoluble in water and has a vapor pressure is 1 mm Hg at 372^oC
Introduction/Dispersion	0.04	5	Can be easily introduced through storm sewers
Process Removal	0.02	4	[AR02]Arsenic compounds can dissolve in water. [AR01] Arsenic can react vigorously with strong oxidizers such as chlorine.
Storability	0.04	3	[AR03]Arsenic loses its luster on exposure to air forming a black modification AS_2O_3
Outcomes	0.28	3	[AR01]Trivalent arsenic compounds are corrosive to the skin however brief contact has no effect. [AR02]Breathing high levels of inorganic arsenic will cause a sore throat or irritated lungs.
Public Perception	0.24	4	Common substance linked to terrorist activity
Composite Score		**3.9**	

Comments:

AR01 Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens Third edition 1991

AR02 www.atsdr.cdc.gov/tfacts2.html

AR03 Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

[AR01]Arsenic Compounds that are classified by the EPA as hazardous substances are : arsenic disulfied, arsenic pentoxide, arsenic trichloride, arsenic trioxide, and arsenic trisulfied

PEL = Permissible Exposure Limit. The legal exposure limit established by OSHA for TWA exposure in any 8 hour work shift during a 40 hour work week.

Table 8.6 Arsenic Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	5	[AR01]Arsenic is used as a pesticide, herbicide, larvacide, and insecticide. Arsenic is used to preserve wood and used in many industrial processes.
Potency	0.11	3	Unknown
Persistence	0.10	4	[AR02]Arsenic cannot be destroyed in the environment it can only change its form. [AR03]Arsenic is insoluble in water and has a vapour pressure is 1 mm Hg at 372^{o}C
Introduction/Dispersion	0.11	5	Can be easily introduced through storm sewers
Process Removal	0.09	4	[AR02]Arsenic compounds can dissolve in water. [AR01] Arsenic can react vigorously with strong oxidizers such as chlorine.
Storability	0.07	3	[AR03]Arsenic loses its luster on exposure to air forming a black modification AS_2O_3
Outcomes	0.26	3	Unknown
Public Perception	0.02	4	Common substance linked to terrorist activity
Composite Score		**3.9**	

Comments:

AR01 Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens Third edition 1991

AR02 www.atsdr.cdc.gov/tfacts.pdf

AR03 Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

[AR01]Arsenic Compounds that are classified by the EPA as hazardous substances are : arsenic disulfied, arsenic pentoxide, arsenic trichloride, arsenic trioxide, and arsenic trisulfied

Table 8.7 Arsenic Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	5	[AR01]Arsenic is used as a pesticide, herbicide, larvacide, and insecticide. Arsenic is used to preserve wood and used in many industrial processes.
Potency	0.06	3	Unknown
Persistence	0.05	4	[AR02]Arsenic cannot be destroyed in the environment it can only change its form. [AR03]Arsenic is insoluble in water and has a vapour pressure is 1 mm Hg at 372^{o}C
Introduction/Dispersion	0.06	5	Can be easily introduced through storm sewers
Process Removal	0.04	4	[AR02]Arsenic compounds can dissolve in water. [AR01] Arsenic can react vigorously with strong oxidizers such as chlorine.
Storability	0.02	3	[AR03]Arsenic loses its luster on exposure to air forming a black modification AS_2O_3
Outcomes	0.32	3	Unknown
Public Perception	0.29	4	Common substance linked to terrorist activity
Composite Score		**3.8**	

Comments:

AR01 Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens Third edition 1991

AR02 www.atsdr.cdc.gov/tfacts.pdf

AR03 Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

[AR01]Arsenic Compounds that are classified by the EPA as hazardous substances are : arsenic disulfied, arsenic pentoxide, arsenic trichloride, arsenic trioxide, and arsenic trisulfied

Table 8.8 Arsenic Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	5	[AR01]Arsenic is used as a pesticide, herbicide, larvacide, and insecticide. Arsenic is used to preserve wood and used in many industrial processes.
Potency	0.06	3	Unknown
Persistence	0.16	4	[AR02]Arsenic cannot be destroyed in the environment it can only change its form. [AR03]Arsenic is insoluble in water and has a vapour pressure is 1 mm Hg at 372^{o}C
Introduction/Dispersion	0.03	5	Can be easily introduced through storm sewers
Process Removal	0.16	4	[AR02]Arsenic compounds can dissolve in water. [AR01] Arsenic can react vigorously with strong oxidizers such as chlorine.
Storability	0.03	3	[AR03]Arsenic loses its luster on exposure to air forming a black modification AS_2O_3
Outcomes	0.20	3	Unknown
Public Perception	0.33	4	Common substance linked to terrorist activity
Composite Score		**3.8**	

Comments:

AR01 Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens Third edition 1991

AR02 www.atsdr.cdc.gov/tfacts.pdf

AR03 Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

[AR01]Arsenic Compounds that are classified by the EPA as hazardous substances are : arsenic disulfied, arsenic pentoxide, arsenic trichloride, arsenic trioxide, and arsenic trisulfied

Table 8.9 *Botulinum Toxin* Worker/Public Health

Criterion	Worker/Public Health		
	Weighting Factor	Score	Comments
Availability	0.18	2	[BT01]Clostridium Botulinum is a spore forming obligat whose natural habitat is the soil and can be easily isolated. Not all of the 19000 Liters of Botulinum Toxin Iraq has admitted to producing has been accounted for and constitutes more than three times the amount needed to kill the current human population.
Potency	0.16	5	[BT02]Lethal dose for a 70 kg person is estimated to be between 0.7 and 0.9 μg/kg for inhalation
Persistence	0.04	4	[BT02]Spores may survive boiling for up to 3 to 4 hours. Botulinum Toxin is inactivated in fresh water within 3 to 6 days.
Introduction/Dispersion	0.04	5	Could be easily introduced into storm sewers.
Process Removal	0.02	3	[BT02] Spores are readily killed by chlorine (either as chlorinated water or as hypochlorite). Spores are resistant to ultraviolet light.
Storability	0.04	5	[BT02]Spores are resistant to dessication and can survive for years in a dry state
Outcomes	0.28	5	[BT02]The fatality rate for food borne botulism is 5-10% and 15-44% for wound botulism. It is assumed that similar rates would exist for inhalation of botulinum toxin.
Public Perception	0.24	5	Botulinum Toxin is an exotic substance that has been linked to terrorist activities.
Composite Score		**4.4**	

Comments:

[BT01] http://jama.ama-assn.org/cgi/content/full/285/8/1059

[BT02] http://www.idsociety.org/Template.cfm?Section=Botulism1&CONTENTID=11058&TEMPLATE=/ContentManagement/ContentDisplay.cfm

Table 8.10 *Botulinum Toxin* Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	2	[BT01]Clostridium Botulinum is a spore forming obligat whose natural habitat is the soil and can be easily isolated. Not all of the 19000 Liters of Botulinum Toxin Iraq has admitted to producing has been accounted for and constitutes more than three times the amount needed to kill the current human population.
Potency	0.11	4	Unknown
Persistence	0.10	4	[BT02]Spores may survive boiling for up to 3 to 4 hours. Botulinum Toxin is inactivated in fresh water within 3 to 6 days.
Introduction/Dispersion	0.11	5	Could be easily introduced into storm sewers.
Process Removal	0.09	3	[BT02] Spores are readily killed by chlorine (either as chlorinated water or as hypochlorite). Spores are resistant to ultraviolet light.
Storability	0.07	5	[BT02]Spores are resistant to dessication and can survive for years in a dry state
Outcomes	0.26	3	Unknown
Public Perception	0.02	5	Botulinum Toxin is an exotic substance that has been linked to terrorist activities.
	Composite Score	**3.4**	

Comments:

[BT01] http://jama.ama-assn.org/cgi/content/full/285/8/1059

[BT02] http://www.idsociety.org/Template.cfm?Section=Botulism1&CONTENTID=11058&TEMPLATE=/ContentManagement/ContentDisplay.

Table 8.11 *Botulinum Toxin* Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	2	[BT01]Clostridium Botulinum is a spore forming obligat whose natural habitat is the soil and can be easily isolated. Not all of the 19000 Liters of Botulinum Toxin Iraq has admitted to producing has been accounted for and constitutes more than three times the amount needed to kill the current human population.
Potency	0.06	4	Unknown
Persistence	0.05	4	[BT02]Spores may survive boiling for up to 3 to 4 hours. Botulinum Toxin is inactivated in fresh water within 3 to 6 days.
Introduction/Dispersion	0.06	5	Could be easily introduced into storm sewers.
Process Removal	0.04	3	[BT02] Spores are readily killed by chlorine (either as chlorinated water or as hypochlorite). Spores are resistant to ultraviolet light.
Storability	0.02	5	[BT02]Spores are resistant to dessication and can survive for years in a dry state
Outcomes	0.32	1	Little or no damage or destruction is expected from the presence of bolutinum toxin in the wastewater collection and treatment system.
Public Perception	0.29	5	Botulinum Toxin is an exotic substance that has been linked to terrorist activities.
Composite Score		**3.0**	

Comments:

[BT01] http://jama.ama-assn.org/cgi/content/full/285/8/1059

[BT02] http://www.idsociety.org/Template.cfm?Section=Botulism1&CONTENTID=11058&TEMPLATE=/ContentManagement/ContentDisplay.

Table 8.12 *Botulinum Toxin* Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	2	[BT01]Clostridium Botulinum is a spore forming obligat whose natural habitat is the soil and can be easily isolated. Not all of the 19000 Liters of Botulinum Toxin Iraq has admitted to producing has been accounted for and constitutes more than three times the amount needed to kill the current human population.
Potency	0.06	4	Unknown
Persistence	0.16	4	[BT02]Spores may survive boiling for up to 3 to 4 hours. Botulinum Toxin is inactivated in fresh water within 3 to 6 days.
Introduction/Dispersion	0.03	5	Could be easily introduced into storm sewers.
Process Removal	0.16	3	[BT02] Spores are readily killed by chlorine (either as chlorinated water or as hypochlorite). Spores are resistant to ultraviolet light.
Storability	0.03	5	[BT02]Spores are resistant to dessication and can survive for years in a dry state
Outcomes	0.20	1	Botulinum Toxin would be inactivated and dliuted in the environment once it passed through the treatment plant.
Public Perception	0.33	5	Botulinum Toxin is an exotic substance that has been linked to terrorist activities.
Composite Score		**3.6**	

Comments:

[BT01] http://jama.ama-assn.org/cgi/content/full/285/8/1059

[BT02] http://www.idsociety.org/Template.cfm?Section=Botulism1&CONTENTID=11058&TEMPLATE=/ContentManagement/ContentDisplay.

Table 8.13 *Bacillas anthracis* Worker/Public Health

Criterion	Worker/Public Health Exposure		
	Weighting Factor	Score	Comments
Availability/ Volume Req'd	0.18	3	[AX01]Since Anthrax is an animal disease that may occur in many parts of the world, soil samples may make anthrax readily available at numerous locations worldwide. Additionally, approximately 1,500 international microbiological repositories sell anthrax cultures. *Bacillus anthracis* can be produced with common biological production equipment.
Potency	0.16	2	[AX02]WaterISAC lists an infective dose of 6,000 - 50,000 spores for inhalation. [AX03]ID_{50} of 8,000 - 10,000 spores.
Persistence	0.04	5	[1]Anthrax Spores can remain viable for two years. The spores have been known to remain viable for decades in aqueous environments.
Introduction/Dispersion	0.04	5	Easily introduced into the wastewater collection and treatment system. No equipment is required to introduce or disperse the contaminant. The contaminant is easily dispersed in the wastewater
Process Removal	0.02	3	Spores are resistant to chlorine. Sodium hypochlorite as a sporicide is applicable under an emergency exemption: The sporicidal effectiveness of hypochlorite solutions depends on the concentration of free available chlorine and pH. (1) Chemical Sterilization: Method: Free available chlorine. Concentration: 2.4 -2.3 mg/L available Cl2, pH 7.2, 22°C. Inoculum size: 1.1 x 10^5 spore suspension of B. anthracis. Time: 1 hour. Efficiency: >99.99 % killed (1 spore/mL survived). (2) Chemical Sterilization: Method: Sodium hypochlorite (NaOCl). Concentration: 0.05 %, pH 7.0, 20°C. Inoculum Size: Spore suspension of B. subtilius globigii, representing 1.6 - 2.2 x 10^9 CFU/mL. Time: 30 minutes. Efficiency: 99.99 % killed. (3) Chemical Sterilization: Chlorine dioxide (ClO2). Concentration: 6-7 mg/L, 20% -40% RH, 23°C. Inoculum sixe: 10^6 spores/biologic indicator.
Storability	0.04	5	[AX01]Anthrax Spores can remain viable for years. The spores have been known to remain viable for decades in aqueous environments.
Outcomes	0.28	4	[AX02]Expected fatality rate between 45% to 75% from inhalation (if treated); Dermal mortailty rate is usually < 1%.
Public Perception	0.24	5	Exotic substance linked to terrorist activities. Much public fear exist surrounding anthrax following the anthrax attacks on the USMail in 2001.
Composite Score		**3.83**	

Comments:

[AX01]Davis, J., Johnson-Wingar, A. *The Anthrax Terror DOD's Number-One Biological Threat* Aerospace Power Journal Winter 2000

[AX02]WaterISAC

[AX03]www.cdc.gov/ncidod/EID/vol5no4/cieslak.htm

ID_{50} = Immediately dangerous to 50% of the exposed population

Table 8.14 *Bacillas anthracis* Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability/ Necessary Quantity	0.24	3	[AX01]Since Anthrax is an animal disease that may occur in many parts of the world, soil samples may make anthrax readily available at numerous locations worldwide. Additionally, approximately 1,500 international microbiological repositories sell anthrax cultures. *Bacillus anthracis* can be produced with common biological production equipment.
Potency	0.11	3	Unknown
Persistence	0.10	5	[AX01]Anthrax Spores can remain viable for two years. The spores have been known to remain viable for decades in aqueous environments.
Introduction/Dispersion	0.11	5	Easily introduced into the wastewater collection and treatment system. No equipment is required to introduce or disperse the contaminant. The contaminant is easily dispersed in the wastewater
Process Removal	0.09	3	Spores are resistant to chlorine. Sodium hypochlorite as a sporicide is applicable under an emergency exemption: The sporicidal effectiveness of hypochlorite solutions depends on the concentration of free available chlorine and pH. (1) Chemical Sterilization: Method: Free available chlorine. Concentration: 2.4 -2.3 mg/L available Cl2, pH 7.2, 22°C. Inoculum size: 1.1 x 10^5 spore suspension of B. anthracis. Time: 1 hour. Efficiency: >99.99 % killed (1 spore/mL survived). (2) Chemical Sterilization: Method: Sodium hypochlorite (NaOCl). Concentration: 0.05 %, pH 7.0, 20°C. Inoculum Size: Spore suspension of B. subtilius globigii, representing 1.6 - 2.2 x 10^9 CFU/mL. Time: 30 minutes. Efficiency: 99.99 % killed. (3) Chemical Sterilization: Chlorine dioxide (ClO2). Concentration: 6-7 mg/L, 20% -40% RH, 23°C. Inoculum sixe: 10^6 spores/biologic indicator.
Storability	0.07	5	[AX01]Anthrax Spores can remain viable for years. The spores have been known to remain viable for decades in aqueous environments.
Outcomes	0.26	3	Unknown
Public Perception	0.02	5	Exotic substance linked to terrorist activities. Much public fear exist surrounding anthrax following the anthrax attacks on the USMail in 2001.
	Composite Score	**3.60**	

Comments:

[AX01]Davis, J., Johnson-Wingar, A. *The Anthrax Terror DOD's Number-One Biological Threat* Aerospace Power Journal Winter 2000

Table 8.15 *Bacillas anthracis* Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	3	[AX01]Since Anthrax is an animal disease that may occur in many parts of the world, soil samples may make anthrax readily available at numerous locations worldwide. Additionally, approximately 1,500 international microbiological repositories sell anthrax cultures. *Bacillus anthracis* can be produced with common biological production equipment.
Potency	0.06	4	Specific remediation procedures for a wastewater collection and treatment system are not in the open literature. Over 80 million dollars was spent on the remediation of one post office to remediate the anthrax mail attacks in 2001.
Persistence	0.05	5	[AX01]Anthrax Spores can remain viable for two years. The spores have been known to remain viable for decades in aqueous environments.
Introduction/Dispersion	0.06	5	Easily introduced into the wastewater collection and treatment system. No equipment is required to introduce or disperse the contaminant. The contaminant is easily dispersed in the wastewater collection and treatment system.
Process Removal	0.04	3	Spores are resistant to chlorine. Sodium hypochlorite as a sporicide is applicable under an emergency exemption: The sporicidal effectiveness of hypochlorite solutions depends on the concentration of free available chlorine and pH. (1) Chemical Sterilization: Method: Free available chlorine. Concentration: 2.4 -2.3 mg/L available Cl2, pH 7.2, 22°C. Inoculum size: 1.1 x 10^5 spore suspension of B. anthracis. Time: 1 hour. Efficiency: >99.99 % killed (1 spore/mL survived). (2) Chemical Sterilization: Method: Sodium hypochlorite (NaOCl). Concentration: 0.05 %, pH 7.0, 20°C. Inoculum Size: Spore suspension of B. subtilius globigii, representing 1.6 - 2.2 x 10^9 CFU/mL. Time: 30 minutes. Efficiency: 99.99 % killed. (3) Chemical Sterilization: Chlorine dioxide (ClO2). Concentration: 6-7 mg/L, 20% -40% RH, 23°C. Inoculum sixe: 10^6 spores/biologic indicator.
Storability	0.02	5	[AX01]Anthrax Spores can remain viable for years. The spores have been known to remain viable for decades in aqueous environments.
Outcomes	0.32	4	Serious effects expected. Treatment plant/ collection system is destroyed or inactivated. Remediation would be required to remove or inactivate the spores. Specific remediation procedures for a wastewater collection and treatment system are not in the open literature. Over 80 million dollars was spent on the remediation of one post office to remediate the anthrax mail attacks in 2001.
Public Perception	0.29	5	Exotic substance linked to terrorist activities. Much public fear exist surrounding anthrax following the anthrax attacks on the USMail in 2001.
	Composite Score	**4.22**	

Comments:

[AX01]Davis, J., Johnson-Wingar, A. *The Anthrax Terror DOD's Number-One Biological Threat* Aerospace Power Journal Winter 2000

Table 8.16 *Bacillas anthracis* Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	3	[AX01]Since Anthrax is an animal disease that may occur in many parts of the world, soil samples may make anthrax readily available at numerous locations worldwide. Additionally, approximately 1,500 international microbiological repositories sell anthrax cultures. *Bacillus anthracis* can be produced with common biological production equipment.
Potency	0.06	3	[AX01]Anthrax Spores can remain viable for two years. The spores have been known to remain viable for decades in aqueous environments. If the spores pass through the plant and remained viable, dilution and sedimentation would be the primary mechanisms of environmental removal.
Persistence	0.16	5	[1]Anthrax Spores can remain viable for years. The spores have been known to remain viable for decades in aqueous environments.
Introduction/Dispersion	0.03	5	Easily introduced into the wastewater collection and treatment system. No equipment is required to introduce or disperse the contaminant. The contaminant is easily dispersed in the wastewater
Process Removal	0.16	3	Spores are resistant to chlorine. Sodium hypochlorite as a sporicide is applicable under an emergency exemption: The sporicidal effectiveness of hypochlorite solutions depends on the concentration of free available chlorine and pH. (1) Chemical Sterilization: Method: Free available chlorine. Concentration: 2.4 -2.3 mg/L available Cl2, pH 7.2, 22°C. Inoculum size: 1.1 x 10^5 spore suspension of B. anthracis. Time: 1 hour. Efficiency: >99.99 % killed (1 spore/mL survived). (2) Chemical Sterilization: Method: Sodium hypochlorite (NaOCl). Concentration: 0.05 %, pH 7.0, 20°C. Inoculum Size: Spore suspension of B. subtilius globigii, representing 1.6 - 2.2 x 10^9 CFU/mL. Time: 30 minutes. Efficiency: 99.99 % killed. (3) Chemical Sterilization: Chlorine dioxide (ClO2). Concentration: 6-7 mg/L, 20% -40% RH, 23°C. Inoculum sixe: 10^6 spores/biologic indicator.
Storability	0.03	5	[AX01]Anthrax Spores can remain viable for years. The spores have been known to remain viable for decades in aqueous environments.
Outcomes	0.20	3	[AX01]Anthrax Spores can remain viable for years. The spores have been known to remain viable for decades in aqueous environments. If the spores pass through the plant and remained viable, dilution and sedimentation would be the primary mechanisms of environmental removal.
Public Perception	0.33	5	Exotic substance linked to terrorist activities. Much public fear exist surrounding anthrax following the anthrax attacks on the USMail in 2001.
Composite Score		**4.10**	

Comments:

[AX01]Davis, J., Johnson-Wingar, A. *The Anthrax Terror DOD's Number-One Biological Threat* Aerospace Power Journal Winter 2000

Table 8.17 Cesium 137 Worker/Public Health

Criterion	Worker/Public Health Exposure		
	Weighting Factor	Score	Comments
Availability	0.18	2	[CE01]Thousands of measuring devices and medical cancer therapy treatments use Cesium 137
Potency	0.16	4	[CE02]The Nuclear Regulatory Commission has set limits for radioactive cesium in workplace air of 4x10[8] microcurie per milliter
Persistence	0.04	5	[CE01]Half Life of 30.17 years
Introduction/Dispersion	0.04	3	Could require some specialized equipment and knowledge
Process Removal	0.02	3	[CE02]Most cesium compounds dissolve in water
Storability	0.04	5	Long storage/half-life
Outcomes	0.28	4	[CE01]Decays by the emission of beta particles and gamma rays.
Public Perception	0.24	4	Much public fear is associated with radioactive materials.
Composite Score		**3.7**	

Comments:

[CE01]http://www.epa.gov/radiation/radionuclides/cesium.htm

[CE02]http://www.atsdr.cdc.gov/tfacts157.html

Table 8.18 Cesium 137 Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	2	[CE01]Thousands of measuring devices and medical cancer therapy treatments use cesium 137
Potency	0.11	3	Unknown
Persistence	0.10	5	[CE01]Half Life of 30.17 years
Introduction/Dispersion	0.11	3	Could require some specialized equipment and knowledge
Process Removal	0.09	3	[CE02]Most cesium compounds dissolve in water
Storability	0.07	5	Long storage/half-life
Outcomes	0.26	2	Unknown
Public Perception	0.02	4	Much public fear is associated with radioactive materials.
Composite Score		2.9	

Comments:

[CE01]http://www.epa.gov/radiation/radionuclides/cesium.htm

[CE02]http://www.atsdr.cdc.gov/tfacts157.html

Table 8.19 Cesium 137 Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	2	[CE01]Thousands of measuring devices and medical cancer therapy treatments use cesium 137
Potency	0.06	4	Unknown
Persistence	0.05	5	[CE01]Half Life of 30.17 years
Introduction/Dispersion	0.06	3	Could require some specialized equipment and knowledge
Process Removal	0.04	3	[CE02]Most cesium compounds dissolve in water
Storability	0.02	5	Long storage/half-life
Outcomes	0.32	4	Contamination of wastewater collection systems and treatment facilities could require remediation.
Public Perception	0.29	4	Much public fear is associated with radioactive materials.
Composite Score		**3.7**	

Comments:

[CE01]http://www.epa.gov/radiation/radionuclides/cesium.htm

[CE02]http://www.atsdr.cdc.gov/tfacts157.html

Table 8.20 Cesium 137 Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	2	[CE01] Thousands of measuring devices and medical cancer therapy treatments use cesium 137
Potency	0.06	4	Unknown
Persistence	0.16	5	[CE01] Half Life of 30.17 years
Introduction/Dispersion	0.03	3	Could require some specialized equipment and knowledge
Process Removal	0.16	3	[CE02] Most cesium compounds dissolve in water
Storability	0.03	5	Long storage/half-life
Outcomes	0.20	3	[CE01] Decays by the emission of beta particles and gamma rays.
Public Perception	0.33	4	Much public fear is associated with radioactive materials.
Composite Score		**3.7**	

Comments:

[CE01] http://www.epa.gov/radiation/radionuclides/cesium.htm

[CE02] http://www.atsdr.cdc.gov/tfacts157.html

Table 8.21 Chlorine Dioxide Worker/Public Health

Criterion	Worker/Public Health		
	Weighting Factor	Score	Comments
Availability	0.18	5	[CD01]Chlorine dioxide is a manufactured gas. It does not occur naturally in the environment. Chlorine dioxide is used as a bleaching agent in paper manufacturing and disinfection in water treatment plants. It is also used for decontamination.
Potency	0.16	5	[CD02]ACGIH TLV is 0.1 ppm OSHA PEL is 0.1 ppm (0.3 mg/m^3) NIOSH REL is 0.1 ppm
Persistence	0.04	2	[CD01]Chlorine dioxide ia a very reactive compound and breaks down quickly in the environment. In water chlorine dioxide quickly forms chlorite. [CD02]The solubility in water is 0.8g/100ml at 20°C and the vapor pressure is 101 kPa.
Introduction/Dispersion	0.04	4	Household equipment is required to introduce of disperse in the environment.
Process Removal	0.02	1	This oxidant would be removed with time in wastewater collection and treatment systems.
Storability	0.04	2	[CD04]Chlorine dioxide is a very unstable material even at room temperature and will explode on impact.
Outcomes	0.28	3	[CD03]Chlorine dioxide is corrosive to the eyes, skin, and respiratory tract. Inhalation can cause pulmonary edema, a medical emergency that can be delayed for several hours. This can cause
Public Perception	0.24	2	This common chemical has not been linked to terrorist activities.
Composite Score		**3.38**	

Comments:

[CD01] http://www.atsdr.cdc.gov/tfacts160.html

[CD02] http://www.cdc.gov/niosh/ipcsneng/neng0127.html

[CD03] Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

[CD04] http://www.osha.gov/SLTC/healthguidelines/chlorinedioxide/recognition.html

REL = Recommended Exposure Limit

TLV = Threshold Limit Value

Table 8.22 Chlorine Dioxide Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	5	[CD01]Chlorine dioxide is a manufactured gas. It does not occur naturally in the environment. Chlorine dioxide is used as a bleaching agent in paper manufacturing and disinfection in water treatment plants. It is also used for decontamination.
Potency	0.11	3	Sufficient quantities of this oxidant may affect the function of the secondary treatment process.
Persistence	0.10	2	[CD01]Chlorine dioxide ia a very reactive compound and breaks down quickly in the environment. In water chlorine dioxide quickly forms chlorite. [CD02]The solubility in water is 0.8g/100ml at 20°C and the vapor pressure is 101 kPa.
Introduction/Dispersion	0.11	4	Household equipment is required to introduce of disperse in the environment.
Process Removal	0.09	1	
Storability	0.07	2	[CD04]Chlorine dioxide is a very unstable material even at room temperature and will explode on impact.
Outcomes	0.26	3	Managable effects expected. Possible loss of biomass in secondary treatment process.
Public Perception	0.02	2	This common chemical has not been linked to terrorist activities.
Composite Score		**3.23**	

Comments:

[CD01] http://www.atsdr.cdc.gov/tfacts160.html

[CD02] http://www.cdc.gov/niosh/ipcsneng/neng0127.html

[CD03] Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

[CD04] http://www.osha.gov/SLTC/healthguidelines/chlorinedioxide/recognition.html

Table 8.23 Chlorine Dioxide Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	5	[CD01]Chlorine dioxide is a manufactured gas. It does not occur naturally in the environment. Chlorine dioxide is used as a bleaching agent in paper manufacturing and disinfection in water treatment plants. It is also used for decontamination.
Potency	0.06		[CD02]Explosive limits, vol% in air >10
Persistence	0.05	2	[CD01]Chlorine dioxide ia a very reactive compound and breaks down quickly in the environment. In water chlorine dioxide quickly forms chlorite. [CO02]The solubility in water is 0.8g/100ml at 20°C and the vapor pressure is 101 kPa.
Introduction/Dispersion	0.06	4	Household equipment is required to introduce of disperse in the environment.
Process Removal	0.04	1	This oxidant would be removed with time in wastewater collection and treatment systems.
Storability	0.02	2	[CD04]Chlorine dioxide is a very unstable material even at room temperature and will explode on impact.
Outcomes	0.32	4	[CD02]May explode on heating, on exposure to sunlight or if subjected to shock or sparks
Public Perception	0.29	2	This common chemical has not been linked to terrorist activities.
Composite Score		**3.09**	

Comments:

[CD01] http://www.atsdr.cdc.gov/tfacts160.html

[CD02] http://www.cdc.gov/niosh/ipcsneng/neng0127.html

[CD03] Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

[CD04] http://www.osha.gov/SLTC/healthguidelines/chlorinedioxide/recognition.html

Table 8.24 Chlorine Dioxide Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	5	[CD01]Chlorine dioxide is a manufactured gas. It does not occur naturally in the environment. Chlorine dioxide is used as a bleaching agent in paper manufacturing and disinfection in water treatment plants. It is also used for decontamination.
Potency	0.06	1	This oxidant should not be able to pass through the treatment plant into the environment.
Persistence	0.16	2	[CD01]Chlorine dioxide ia a very reactive compound and breaks down quickly in the environment. In water chlorine dioxide quickly forms chlorite. [CD02]The solubility in water is 0.8g/100ml at 20°C and the vapor pressure is 101 kPa.
Introduction/Dispersion	0.03	4	Household equipment is required to introduce of disperse in the environment.
Process Removal	0.16	1	This oxidant would be removed with time in wastewater collection and treatment systems.
Storability	0.03	2	[CD04]Chlorine dioxide is a very unstable material even at room temperature and will explode on impact.
Outcomes	0.20	2	At most, the flora and fauna around the discharge may be affected.
Public Perception	0.33	2	This common chemical has not been linked to terrorist activities.
Composite Score		**1.92**	

Comments:

[CD01] http://www.atsdr.cdc.gov/tfacts160.html

[CD02] http://www.cdc.gov/niosh/ipcsneng/neng0127.html

[CD03] Sittig, Marshall. Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition. 1991.

[CD04] http://www.osha.gov/SLTC/healthguidelines/chlorinedioxide/recognition.html

Table 8.25 Cyanide Salts Worker/Public Health

Criterion	Worker/Public Health		
	Weighting Factor	Score	Comments
Availability	0.18	4	Not publicly available.[CY08]Facilities in the U.S. producing sodium cyanide in 2005 include: Cyano Co. in Nevada and Du Pont Chemical Company in Tennessee. Cyanide substances also occur naturally in the fruits, seeds, roots and leaves of numerous plants, and cyanide is released to the environment from natural biogenic processes from higher plants, bacteria and fungi. Used as a pesticide and in mining, manufacturing and non-manufacturing industry.
Potency	0.16	3	[CY01]Sodium Cyanide OSHA PEL = 5mg/m^3. [CY02]Hydrogen Cyanide Inhalation OSHA PEL = 10ppm for inhalation. [CY05]Cyanide poisoning by dermal contact with water is not considered a significant health risk.
Persistence	0.04	4	[CY03]Cyanide salts in surface water will form hydrogen cyanide. The half life of hydrogen cyanide in the atmosphere is 1 to 3 years. Most cyanides in water will form hydrogen cyanide and evaporate. Some cyanide in the water will be transformed into less harmful chemicals by microorganisms or will form a complex with metals such as iron. [CY05]At pH values less than 9.2 most of the cyanide in water is present as hydrogen cyanide.
Introduction/Dispersion	0.04	5	Could be introduced into the storm sewer. No special equipment or knowledge needed
Process Removal	0.02	5	[CY03]Some of the cyanide salts will form hydrogen cyanide which will evaporate. [CY04]One of the major sources of cyanides in natural waters are from the discharges of industrial wastewater treatment facilities. [CY05]Generally cyanic compounds do not readily dissolve in water and can be removed by sedimentation or filtration. Free chlorination using hypochlorite will remove cyanide in water, if the pH is equal to or greater than 10; however if the pH is less than 10 the reaction may produce cyanogen chloride, which is sometimes considered even more toxic than molecular hydrogen cyanide. Aeration conducted at room temperature on water with a pH level above 9.2 may be effective for removing hydrogen cyanide and cyanogen chloride. If the pH level is below 9.2, the cyanide removal efficiency will increase compared to higher pH values.
Storability	0.04	5	Can be stored in a dry place for extended periods.
Outcomes	0.28	4	[CY06]Can cause weakness, headaches, confusion, nausea, vomiting, eye and skin irritation, slow gasping respiration
Public Perception	0.24	5	Exotic substance linked to terrorist activities.
Composite Score		**4.2**	

Comments:

[CY01]http://www.cdc.gov/niosh/npg/npgd0562.html

[CY02]http://www.atsdr.cdc.gov/MHMI/mmg8.html

[CY03]http://www.atsdr.cdc.gov/tfacts8.html

[CY04]http://www.atsdr.cdc.gov/toxprofiles/tp8-c1-b.pdf

[CY05]Whelton, A., Jensen, J., Richards, T., Valdivia, R., *The Cyanic Threat To Potable Water* Civil Engineering Pages 50 -54 and 84

[CY06]Handbook of Toxic and Hazardous Chemicals and Carcinogens Second Edition

[CY08]http://www.atsdr.cdc.gov/toxprofiles/tp8.html

Table 8.26 Cyanide Salts Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	4	Not publically available.[CY08] Facilities in the U.S. producing sodium cyanide in 2005 include: Cyano Co. in Nevada and Du Pont Chemical Company in Tennessee. Cyanide substances also occur naturally in the fruits, seeds, roots and leaves of numerous plants, and cyanide is released to the environment from natural biogenic processes from higher plants, bacteria and fungi. Used as a pesticide and in mining, manufacturing and non-manufacturing industry.
Potency	0.11	3	Unknown
Persistence	0.10	4	[CY03] Cyanide salts in surface water will form hydrogen cyanide. The half life of hydrogen cyanide in the atmosphere is 1 to 3 years. Most cyanides in water will form hydrogen cyanide and evaporate. Some cyanide in the water will be transformed into less harmful chemicals by microorganisms or will form a complex with metals such as iron. [CY05] At pH values less than 9.2 most of the cyanide in water is present as hydrogen cyanide.
Introduction/Dispersion	0.11	5	Could be introduced into the storm sewer. No special equipment or knowledge needed
Process Removal	0.09	5	[CY03] Some of the cyanide salts will form hydrogen cyanide which will evaporate. [CY04] One of the major sources of cyanides in water are discharges from publicly owned wastewater treatment facilities. [CY05] Generally cyanic compounds do not readily dissolve in water and can be removed by sedimentation or filtration. Free chlorination using hypochlorite will remove cyanide in water if the pH is equal to or greater than 10; however if the pH is less than 10 the reaction may produce cyanogen chloride, which is sometimes considered even more toxic than molecular hydrogen cyanide. Aeration conducted at room temperature on water with a pH level above 9.2 may be effective for removing hydrogen cyanide and cyanogen chloride. If the pH level is below 9.2 the cyanide removal will be
Storability	0.07	5	Can be stored in a dry place for extended periods.
Outcomes	0.26	3	No data has yet to be obtained by this research group concerning the effects of cyanide on wastewater treatment plant microbes.
Public Perception	0.02	5	Exotic substance linked to terrorist activities.
Composite Score		**3.9**	

Comments:

[CY03] http://www.atsdr.cdc.gov/tfacts8.html

[CY04] http://wwwatsdr.cdc.gov/toxprofiles/tp8-c1-b.pdf

[CY05] Whelton, A., Jensen, J., Richards, T., Valdivia, R., *The Cyanic Threat To Potable Water* Civil Engineering Pages 50 -54 and 84

[CY08] http://www.atsdr.cdc.gov/toxprofiles

Table 8.27 Cyanide Salt Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	4	Not publicly available.[CY08] Facilities in the U.S. producing sodium cyanide in 2005 include: Cyano Co. in Nevada and Du Pont Chemical Company in Tennessee. Cyanide substances also occur naturally in the fruits, seeds, roots and leaves of numerous plants, and cyanide is released to the environment from natural biogenic processes from higher plants, bacteria and fungi. Used as a pesticide and in mining, manufacturing and non-manufacturing industry.
Potency	0.06	1	Will volatize into hydrogen cyanide and be diluted into the atmosphere.
Persistence	0.05	4	[CY03] Cyanide salts in surface water will form hydrogen cyanide. The half life of hydrogen cyanide in the atmosphere is 1 to 3 years. Most cyanides in water will form hydrogen cyanide and evaporate. Some cyanide in the water will be transformed into less harmful chemicals by microorganisms or will form a complex with metals such as iron. [CY05] At pH values less than 9.2 most of the cyanide in water is present as hydrogen cyanide.
Introduction/Dispersion	0.06	5	Could be introduced into the storm sewer. No special equipment or knowledge needed
Process Removal	0.04	5	[CY03] Some of the cyanide salts will form hydrogen cyanide which will evaporate. [CY04] One of the major sources of cyanides in water are discharges from publicly owned wastewater treatment facilities. [CY05] Generally cyanic compounds do not readily dissolve in water and can be removed by sedimentation or filtration. Free chlorination using hypochlorite will remove cyanide in water if the pH is equal to or greater than 10; however if the pH is less than 10 the reaction may produce cyanogen chloride, which is sometimes considered even more toxic than molecular hydrogen cyanide. Aeration conducted at room temperature on water with a pH level above 9.2 may be effective for removing hydrogen cyanide and cyanogen chloride. If the pH level is below 9.2 the cyanide removal will be
Storability	0.02	5	Can be stored in a dry place for extended periods.
Outcomes	0.32	1	Not considered a significant damage/destruction risk
Public Perception	0.29	5	Exotic substance linked to terrorist activities.
Composite Score		**3.3**	

Comments:

[CY03] http://www.atsdr.cdc.gov/tfacts8.html

[CY04] http://wwwatsdr.cdc.gov/toxprofiles/tp8-c1-b.pdf

[CY05] Whelton, A., Jensen, J., Richards, T., Valdivia, R., *The Cyanic Threat To Potable Water* Civil Engineering Pages 50 -54 and 84

[CY08] http://www.atsdr.cdc.gov/toxprofiles

Table 8.28 Cyanide Salt Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	4	Not publicly available.[CY08] Facilities in the U.S. producing sodium cyanide in 2005 include: Cyano Co. in Nevada and Du Pont Chemical Company in Tennessee. Cyanide substances also occur naturally in the fruits, seeds, roots and leaves of numerous plants, and cyanide is released to the environment from natural biogenic processes from higher plants, bacteria and fungi. Used as a pesticide and in mining, manufacturing and non-manufacturing industry.
Potency	0.06	2	Will volatize to hydrogen cyanide and be diluted in the atmosphere.
Persistence	0.16	4	[CY03] Cyanide salts in surface water will form hydrogen cyanide. The half life of hydrogen cyanide in the atmosphere is 1 to 3 years. Most cyanides in water will form hydrogen cyanide and evaporate. Some cyanide in the water will be transformed into less harmful chemicals by microorganisms or will form a complex with metals such as iron. [CY05] At pH values less than 9.2 most of the cyanide in water is present as hydrogen cyanide.
Introduction/Dispersion	0.03	5	Could be introduced into the storm sewer. No special equipment or knowledge needed
Process Removal	0.16	5	[CY03] Some of the cyanide salts will form hydrogen cyanide which will evaporate. [CY04] One of the major sources of cyanides in water are discharges from publicly owned wastewater treatment facilities. [CY05] Generally cyanic compounds do not readily dissolve in water and can be removed by sedimentation or filtration. Free chlorination using hypochlorite will remove cyanide in water if the pH is equal to or greater than 10; however if the pH is less than 10 the reaction may produce cyanogen chloride, which is sometimes considered even more toxic than molecular hydrogen cyanide. Aeration conducted at room temperature on water with a pH level above 9.2 may be effective for removing hydrogen cyanide and cyanogen chloride. If the pH level is below 9.2 the cyanide removal will be even better.
Storability	0.03	5	Can be stored in a dry place for extended periods.
Outcomes	0.20	2	Will volatize to hydrogen cyanide and be diluted in the atmosphere.
Public Perception	0.33	5	Exotic substance linked to terrorist activities.
Composite Score		**4.0**	

Comments:

[CY03] http://www.atsdr.cdc.gov/tfacts8.html

[CY04] http://wwwatsdr.cdc.gov/toxprofiles/tp8-c1-b.pdf

[CY05] Whelton, A., Jensen, J., Richards, T., Valdivia, R., *The Cyanic Threat To Potable Water* Civil Engineering Pages 50 -54 and 84

[CY08] http://www.atsdr.cdc.gov/toxprofiles

Table 8.29 Ethylene Glycol Worker/Public Health

Criterion	Worker/Public Health Exposure		
	Weighting Factor	Score	Comments
Availability	0.18	5	Readily Available. Used as anti-freeze for automobiles
Potency	0.16	2	[EG01]ACGIH ceiling limit (inhalation) = 100mg/m^3 (39 ppm) Acute toxicity tests in seven different fish have found all lethal concentrations (LC_{50}) to be at least 800 milligrams/liter (mg/L); tests with aquatic invertebrates found LC_{50} of at least 500 mg/L. Tests with algae, yeast, protozoa, bacteria and fungi also show that EGBE will not cause adverse effects except at very high concentrations.
Persistence	0.04	3	[EG02]Degraded within several days to a week in water.
Introduction/Dispersion	0.04	5	Could enter through storm sewers. No special equipment or knowledge needed.
Process Removal	0.02	3	[EG03]Studies show that ethylene glycol is readily biodegradable in both aerobic surface waters and under typical wastewater treatment plant conditions.
Storability	0.04	5	Can be stored for more than 6 months.
Outcomes	0.28	2	[EG01]Toxic inhalation is unlikely at room temperature because of low volatility. Ethylene Glycol is only mildly irritating to skin and is poorly absorbed through the skin.
Public Perception	0.24	1	There is little public fear associated with anti-freeze.
Composite Score		**2.6**	

Comments:

[EG01]http://www.atsdr.cdc.gov/MHMI/mmg96.html
[EG02]http://www.atsdr.cdc.gov/tfacts96.html
[EG03]http://www.egep.org/envchar.htm

ACGIH = American Conference of Governmental Industrial Hygienists

Ceiling Limit = Maximum concentration of an airborne contaminant to which an employee may be exposed at any time (Peak Exposure)

LC_{50} = Lethal concentration in 50% of animals tested

Table 8.30 Ethylene Glycol Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	5	Readily Available. Used as anti-freeze for automobiles
Potency	0.11	3	Unknown
Persistence	0.10	3	[EG02]Breaks down within several days to a week in water. [EG03]Log K_{OW} = 0.81 to 0.83, Calculated bioconcentration factor = 2.5
Introduction/Dispersion	0.11	5	Could enter through storm sewers. No special equipment or knowledge needed.
Process Removal	0.09	2	[EG03]Studies show that ethylene glycol is readily biodegradable in both aerobic surface waters and under typical wastewater treatment plant conditions.
Storability	0.07	5	Can be stored for more than 6 months.
Outcomes	0.26	2	Unlikely to cause process upset. An effort is being made to obtain more specific data on this topic.
Public Perception	0.02	1	There is little public fear associated with anti-freeze.
Composite Score		**3.4**	

Comments:

[EG02]http://www.atsdr.cdc.gov/tfacts96.html

[EG03]http://www.egep.org/envchar.htm

Table 8.31 Ethylene Glycol Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	5	Readily Available. Used as anti-freeze for automobiles
Potency	0.06	3	[EG04]Flash point is 111°C (closed cup), Lower Explosive Limit is 3.2 and the Upper Explosive Limit is
Persistence	0.05	3	[EG02]Breaks down within several days to a week in water.
Introduction/Dispersion	0.06	5	Could enter through storm sewers. No special equipment or knowledge needed.
Process Removal	0.04	3	[EG03]Studies show that ethylene glycol is readily biodegradable in both aerobic surface waters and under typical wastewater treatment plant conditions.
Storability	0.02	5	Can be stored for more than 6 months.
Outcomes	0.32	2	[EG04]Flash point is 111°C (closed cup)
Public Perception	0.29	1	There is little public fear associated with anti-freeze.
Composite Score		**2.6**	

Comments:

[EG01]http://www.atsdr.cdc.gov/MHMI/mmg96.html
[EG02]http://www.atsdr.cdc.gov/tfacts96.html
[EG03]http://www.egep.org/envchar.htm
[EG04]http://www.cdc.gov/niosh/ipcsneng/neng0270.html

Table 8.32 Ethylene Glycol Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	5	Readily Available. Used as anti-freeze for automobiles
Potency	0.06	3	Unknown
Persistence	0.16	3	[EG02]Breaks down within several days to a week in water.
Introduction/Dispersion	0.03	5	Could enter through storm sewers. No special equipment or knowledge needed.
Process Removal	0.16	3	[EG03]Studies show that ethylene glycol is readily biodegradable in both aerobic surface waters and under typical wastewater treatment plant conditions.
Storability	0.03	5	Can be stored for more than 6 months.
Outcomes	0.20	2	[EG03]Studies show that ethylene glycol is readily biodegradable in both aerobic surface waters and under typical wastewater treatment plant conditions.
Public Perception	0.33	1	There is little public fear associated with anti-freeze.
	Composite Score	**2.3**	

Comments:

[EG02]http://www.atsdr.cdc.gov/tfacts96.html

[EG03]http://www.egep.org/envchar.htm

Table 8.33 Gasoline Worker/Public Health

Criterion	Worker/Public Health Exposure		
	Weighting Factor	Score	Comments
Availability	0.18	5	Readily Available
Potency	0.16	3	[GA01]OSHA does not list a permissible inhalation exposure limit for gasoline. [GA03]The ACGIH has a TLV as 300 ppm (as TWA) and 500ppm (as STEL)
Persistence	0.04	3	Gasoline will volatilize, Microorganisms will degrade gasoline. However, these microorganisms may not typically be available in wastewater treatment plant processes.
Introduction/Dispersion	0.04	5	Gasoline may be easily introduced into a wastewater collection system. Also, no specialized equipment is required to introduce gasoline into the wastewater collection system.
Process Removal	0.02	5	Gasoline will not settle in the treatment process and the microorganisms will have little effect on degradation in a typical wastewater treatment plant.
Storability	0.04	5	Gasoline can be stored for long periods of time.
Outcomes	0.28	4	Serious effects expected if concentrations are high in the wastewater collection and treatment system. Public notification is required. Treatment plant processes may be temporarily upset and remediation may be required.
Public Perception	0.24	2	No extrordinary public reaction is assoicated with the occurrence of gasoline in wastewater collection and treatment systems.
Composite Score		**3.6**	

Comments:

[GA01] http://www.cdc.gov/niosh/npg/npgd0299.html

[GA03]http://www.cdc.gov/niosh/ipcsneng/neng1400.html

TWA = Time Weighted Average
STEL = Short Term Exposure Limit

Table 8.34 Gasoline Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	5	Readily Available
Potency	0.11	3	Unknown relative to domestic wastewater treatment unit processes.
Persistence	0.10	3	Gasoline will volatilize, Microorganisms will degrade gasoline. However, these microorganisms may not be colonized in wastewater treatment plant processes
Introduction/Dispersion	0.11	5	Gasoline may be easily introduced into a wastewater collection. Also, no specialized equipment is required to introduce gasoline into the wastewater collection system.
Process Removal	0.09	5	Gasoline will not settle in the treatment process and the microorganisms typically present in a wastewater treatment system may have little effect.
Storability	0.07	5	Gasoline can be stored for long periods of time.
Outcomes	0.26	3	The effect of gasoline on the wastewater collection is unknown from a process upset perspective. Microorganisms will degrade gasoline. However, these microorganisms may not typically be available in wastewater treatment plant processes
Public Perception	0.02	2	No extraordinary public reaction is associated with the occurrence of gasoline in wastewater collection and treatment systems.
Composite Score		**4.0**	

Comments:

Table 8.35 Gasoline Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	5	Readily Available
Potency	0.06	5	[GA01]Flash Point: -45° F, LFL: 1.4% , and UFL: 7.6%
Persistence	0.05	3	Gasoline will volatilize, Microorganisms will degrade gasoline. However, these microorganisms may not be colonized in wastewater treatment plant processes
Introduction/Dispersion	0.06	5	Gasoline may be easily introduced into a wastewater collection. Also, no specialized equipment is required to introduce gasoline into the wastewater collection system.
Process Removal	0.04	5	Gasoline will not settle in the treatment process and the microorganisms will have little effect on degradation.
Storability	0.02	5	Gasoline can be stored for long periods of time.
Outcomes	0.32	5	Possible damage and/or destruction of the treatment plant and the collection system. Recent incidents will be described and cited (e.g., Guadalajara, Mexico).
Public Perception	0.29	2	No extraordinary public reaction is associated with the occurrence of gasoline in wastewater collection and treatment systems.
Composite Score		**4.03**	

Comments: [GA01] http://www.cdc.gov/niosh/npg/npgd0299.html

Table 8.36 Gasoline Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	5	Readily Available
Potency	0.06	3	Emergency response plans have been developed and implemented to mitigate the effect of gasoline spills into the environment. These plans combined with the effect of passing gasoline through the treatment should somewhat reduce the adverse effect of gasoline on the environment.
Persistence	0.16	3	Gasoline will volatilize, Microorganisms will degrade gasoline. However, these microorganisms may not be colonized in wastewater treatment plant processes
Introduction/Dispersion	0.03	5	Gasoline may be easily introduced into a wastewater collection. Also, no specialized equipment is required to introduce gasoline into the wastewater collection system.
Process Removal	0.16	5	Gasoline will not settle in the treatment process and the microorganisms will have little effect on degradation.
Storability	0.03	5	Gasoline can be stored for long periods of time.
Outcomes	0.20	1	Once in the environment, gasoline will be removed from water via, degradation, sedimentation or volatilization.
Public Perception	0.33	2	No extraordinary public reaction is associated with the occurrence of gasoline in wastewater collection and treatment systems.
Composite Score		**2.8**	

Comments:

Table 8.37 Kerosene Worker/Public Health

Criterion	Worker/Public Health		
	Weighting Factor	Score	Comments
Availability	0.18	5	Readily available. Can be purchased at most gas stations. [KE01]Common fuel oil
Potency	0.16	3	[KE02] There is no OSHA PEL. NIOSH REL is 100mg/m^3 The substance can be absorbed into the body by inhalation of the vapors and ingestion
Persistence	0.04	3	[KE01]Some chemicals found in fuel oils may evaporate into the air from contaminated water. Some of the chemicals found in fuel oils may be broken down slowly in air, water, and soil by sunlight or small organisms. [KE04]Kerosene is insoluble in water.
Introduction/Dispersion	0.04	5	Can be easily introduced into a storm sewer.
Process Removal	0.02	5	[KE01]Some chemicals found in fuel oils may dissolve in water, they may also stick to particles in water which will eventually cause them to settle to the bottom sediment.
Storability	0.04	5	[KE03]Kerosene does not evaporate as readily as gasoline and will remain stable in storage with no special treatment
Outcomes	0.28	2	[KE02]The substance slightly irritates the skin and the respiratory tract.
Public Perception	0.24	2	No extrordinary public reaction is assoicated with the occurrence of kerosene in wastewater collection and treatment systems.
Composite Score		**3.0**	

Comments:

KE01 http://www.atsdr.cdc.gov/tfacts75.html

KE02 http://www.cdc.gov/niosh/ipcsneng/neng0663.html

KE03 http://members.aol.com/keninga/lp_kero.htm

KE04 Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

PEL = Permissible Exposure Limit. The legal exposure limit established by OSHA for TWA exposure in any 8 hour work shift during a 40 hour work week.

REL = Recommended Exposure Limit. The REL is a recommended exposure limit set by NIOSH based on a 10 hour work shift and a 40 hour work week.

Table 8.38 Kerosene Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	5	Readily available. Can be purchased at most gas stations. [KE01]Common fuel oil
Potency	0.11	3	
Persistence	0.10	3	[KE01]Some chemicals found in fuel oils may evaporate into the air from contaminated water. Some of the chemicals found in fuel oils may be broken down slowly in air, water, and soil by sunlight or small organisms. [KE04]Kerosene is insoluble in water.
Introduction/Dispersion	0.11	5	Can be easily introduced into a storm sewer.
Process Removal	0.09	5	[KE01]Some chemicals found in fuel oils may dissolve in water, they may also stick to particles in water which will eventually cause them to settle to the bottom sediment.
Storability	0.07	5	[KE03]Kerosene does not evaporate as readily as gasoline and will remain stable in storage with no special treatment
Outcomes	0.26	3	
Public Perception	0.02	2	No extrordinary public reaction is assoicated with the occurrence of kerosene in wastewater collection and treatment systems.
Composite Score		**4.0**	

Comments:

KE01 ATSDR TOXFAQs for Fuel Oils

KE02 http://www.cdc.gov/niosh/ipcsneng/neng0663.html

KE03 http://members.aol.com/keninga/lp_kero.htm

KE04 Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

Table 8.39 Kerosene Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	5	Readily available. Can be purchased at most gas stations. [KE01]Common fuel oil
Potency	0.06	5	[KE02]The lower explosive limit (LEL) is 0.7 and the upper explosive limit (UEL) is 5. Flash point 37 - 65°C
Persistence	0.05	3	[KE01]Some chemicals found in fuel oils may evaporate into the air from contaminated water. Some of the chemicals found in fuel oils may be broken down slowly in air, water, and soil by sunlight or small organisms. [KE04]Kerosene is insoluble in water.
Introduction/Dispersion	0.06	5	Can be easily introduced into a storm sewer.
Process Removal	0.04	5	[KE01]Some chemicals found in fuel oils may dissolve in water, they may also stick to particles in water which will eventually cause them to settle to the bottom sediment.
Storability	0.02	5	[KE03]Kerosene does not evaporate as readily as gasoline and will remain stable in storage with no special treatment
Outcomes	0.32	5	Could cause Explosion
Public Perception	0.29	2	No extrordinary public reaction is assoicated with the occurrence of kerosene in wastewater collection and treatment systems.
Composite Score		**4.0**	

Comments:

[KE01] ATSDR TOXFAQs for Fuel Oils

[KE02] http://www.cdc.gov/niosh/ipcsneng/neng0663.html

[KE03] http://members.aol.com/keninga/lp_kero.htm

[KE04] Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

FLASH POINT = The lowest temperature at which a flammable liquid will give off enough vapors to form an ignitable mixture with the air above the surface of the liquid or within its container.

LEL = Lower Explosive Limit. The percentage of vapor in the air below which a fire can't occur because there isn't enough fuel: the mixture is said to be too lean.

UEL = Upper Explosive Limit. The percentage of vapor in the air above which there isn't enough air for a fire: the mixture is said to be too rich.

Table 8.40 Kerosene Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	5	Readily available. Can be purchased at most gas stations. [KE01]Common fuel oil
Potency	0.06	3	
Persistence	0.16	3	[KE01]Some chemicals found in fuel oils may evaporate into the air from contaminated water. Some of the chemicals found in fuel oils may be broken down slowly in air, water, and soil by sunlight or small organisms. [KE04]Kerosene is insoluble in water.
Introduction/Dispersion	0.03	5	Can be easily introduced into a storm sewer.
Process Removal	0.16	5	[KE01]Some chemicals found in fuel oils may dissolve in water, they may also stick to particles in water which will eventually cause them to settle to the bottom sediment.
Storability	0.03	5	[KE03]Kerosene does not evaporate as readily as gasoline and will remain stable in storage with no special treatment
Outcomes	0.20	2	
Public Perception	0.33	2	No extrordinary public reaction is assoicated with the occurrence of kerosene in wastewater collection and treatment systems.
Composite Score		**3.0**	

Comments:

KE01 ATSDR TOXFAQs for Fuel Oils

KE02 http://www.cdc.gov/niosh/ipcsneng/neng0663.html

KE03 http://members.aol.com/keninga/lp_kero.htm

KE04 Prager, Jan C. Environmental Contaminant Reference Databook. 1995 and 1996.

Table 8.41 Malathion Worker/Public Health

Criterion	Worker/Public Health Exposure		
	Weighting Factor	Score	Comments
Availability	0.18	5	[MA01]Malathion is a widely used organophosphorus insecticide.
Potency	0.16	4	[MA01] OSHA PEL = 10 mg/m^3 for skin and TWA limit for respiration is 5 mg/m^3 [MA06]The LC_{50} for fish can range from 27μg/l to 1.9 mg/l depending on the type of fish.
Persistence	0.04	4	[MA03]Malathion's rapid degradation in soils with high microbial activity in many water bodies results in reduced environmental exposures relative to other organophosphate insecticides. [MA04]Half-life ranges from 0.2 weeks at pH 8 and up to 21 weeks at pH 6. [MA02] No solubility in water.
Introduction/Dispersion	0.04	5	No specialized equipment or knowledge needed.
Process Removal	0.02	3	Unknown
Storability	0.04	4	[MA02]Keep in well ventilated room. Chemical will volatize over time.
Outcomes	0.28	5	[MA02]Exposure above the OEL may result in death
Public Perception	0.24	2	Malathion is a common substance not linked to terrorist activities.
Composite Score		**4.0**	

Comments:

[MA01]http://www.cdc.gov/niosh/pel88/121-75.html

[MA02]http://www.hazard.com/msds/mf/cards/file/0172.html

[MA03]www.epa.gov/pesticides/op/malathion/efedresp.pdf

[MA04]http://www.speclab.com/compound/c121755.htm

[MA06]Verschueren, Karel. Handbook of Environmental Data on Organic Chemicals, 4th Edition. 2001.

PEL = Permissible Exposure Limit. The legal exposure limit established by OSHA for TWA exposure in any 8 hour work shift during a 40 hour work week.

LC_{50} = Lethal concentration in 50% of animals tested

TWA = Time Weighted Average. The TWA is a way of measuring the total exposure of a worker to contaminants in work room air in a work day.

OEL = Occupational Exposure Limit

Table 8.42 Malathion Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	5	[MA01]Malathion is a widely used organophosphorus insecticide.
Potency	0.11	4	[MA02] No Solubility in water. Relative density = 1.2, Octanol/water partition coefficient = $10^{2.89}$ This substance is very toxic to aquatic organisms. This substance may be hazardous to the environment. Cholinesterase inhibitor.
Persistence	0.10	4	[MA03]Malathion's rapid degradation in soils with high microbial activity and many water bodies results in reduced environmental exposures relative to other organophosphate insecticides. [MA04]Half-life ranges from 0.2 weeks at pH 8 and up to 21 weeks at pH 6. [MA02] No solubility in water.
Introduction/Dispersion	0.11	5	No specialized equipment or knowledge needed.
Process Removal	0.09	3	Unknown
Storability	0.07	4	[MA02]Keep in well ventilated room.
Outcomes	0.26	3	Unknown
Public Perception	0.02	2	Malathion is a common substance not linked to terrorist activities.
Composite Score		**4.0**	

Comments:

[MA01]http://www.cdc.gov/niosh/pel88/121-75.html
[MA02]http://www.hazard.com/msds/mf/cards/file/0172.html
[MA03]www.epa.gov/pesticides/op/malathion/efedresp.pdf
[MA04]http://www.speclab.com/compound/c121755.htm

Table 8.43 Malathion Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	5	[MA01]Malathion is a widely used organophosphorus insecticide.
Potency	0.06	4	[MA01]Combustible, liquid formulations containing organic solvents may be flammable. Gives off irritating or toxic fumes (or gases) in a fire. Risk of fire and explosion if formulations contain flammable/explosive solvents. [MA05]Flash Point 140°F
Persistence	0.05	4	[MA03]Malathion's rapid degradation in soils with high microbial activity and many water bodies results in reduced environmental exposures relative to other organophosphate insecticides. [MA04]Half-life ranges from 0.2 weeks at pH 8 and up to 21 weeks at pH 6. [MA02] No solubility in water.
Introduction/Dispersion	0.06	5	No specialized equipment or knowledge needed.
Process Removal	0.04	3	Unknown
Storability	0.02	4	[MA02]Keep in a well ventilated room.
Outcomes	0.32	3	Unknown
Public Perception	0.29	2	Malathion is a common substance not linked to terrorist activities.
Composite Score		**3.3**	

Comments:

[MA01]http://www.cdc.gov/niosh/pel88/121-75.html
[MA02]http://www.hazard.com/msds/mf/cards/file/0172.html
[MA03]www.epa.gov/pesticides/op/malathion/efedresp.pdf
[MA04]http://www.speclab.com/compound/c121755.htm
[MA05]http://www.douglasproducts.com/agricultural/msds_mal.html

Table 8.44 Malathion Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	5	[MA01]Malathion is a widely used organophosphorus insecticide
Potency	0.06	4	[MA02] Not Soluble in water. Relative density = 1.2, Octanol/water partition coefficient = $10^{2.89}$ This substance is very toxic to aquatic organisms. This substance may be hazardous to the environment. Cholinesterase inhibitor.
Persistence	0.16	4	[MA03]Malathion's rapid degradation in soils with high microbial activity and many water bodies results in reduced environmental exposures relative to other organophosphate insecticides. [MA04]Half-life ranges from 0.2 weeks at pH 8 and up to 21 weeks at pH 6. [MA02] No solubility in water.
Introduction/Dispersion	0.03	5	No specialized equipment or knowledge needed.
Process Removal	0.16	3	Unknown
Storability	0.03	4	[MA02]Keep in well ventilated room
Outcomes	0.20	4	[MA02]This substance is very toxic to aquatic organisms
Public Perception	0.33	2	Malathion is a common substance not linked to terrorist activities.
Composite Score		**3.2**	

Comments:

[MA01]http://www.cdc.gov/niosh/pel88/121-75.html
[MA02]http://www.hazard.com/msds/mf/cards/file/0172.html
[MA03]www.epa.gov/pesticides/op/malathion/efedresp.pdf
[MA04]http://www.speclab.com/compound/c121755.htm

Table 8.45 Paraquat Worker/Public Health

Criterion	Worker/Public Health Exposure		
	Weighting Factor	Score	Comments
Availability	0.18	5	Widely used herbicide.
Potency	0.16	4	[PA01]OSHA PEL = 0.5mg/m^3 for respiration and skin. Can be absorbed into the body by inhalation of its aerosol, through the skin and by ingestion. [PA03]The 24 hour LC_{50} for a guppy (*Poecilia mexicana*) is 12 mg/l
Persistence	0.04	4	[PA02]Paraquat is adsorbed on suspended matter and on sediment in water. If paraquat is not subject to sorption, it is rapidly degraded by microorganisms. Although paraquat could not be detected after 1 to 4 days on environmental samples, residues were still found in the biosolids after more than 400
Introduction/Dispersion	0.04	5	No specialized equipment or knowledge needed
Process Removal	0.02	3	Unknown
Storability	0.04	4	[PA01]Store in well ventilated room
Outcomes	0.28	4	[PA01]Irritating to the eyes, skin, and respiratory tract. This substance may cause effects on the kidneys liver, and gastrointestinal tract cardiovascular system and lungs resulting in impaired functions, tissue lesions including hemorrhage and lung fibrosis. Exposure to high concentrations could lead to death.
Public Perception	0.24	2	The public does not have an usual fear of this chemical.
Composite Score		**3.7**	

Comments:

[PA01]http://www.cdc.gov/niosh/ipcsneng/neng0005.html

[PA02]http://144.16.93.203/energy/HC270799/HDL/ENV/enven/vol355.htm

[PA03]Verschueren, Karel. Handbook of Environmental Data on Organic Chemicals, 4th Edition. 2001.

PEL = Permissible Exposure Limit. The legal exposure limit established by OSHA for TWA exposure in any 8 hour work shift during a 40 hour work week.

LC_{50} = Lethal concentration in 50% of animals tested

TWA = Time Weighted Average. The TWA is a way of measuring the total exposure of a worker to contaminants in work room air in a work day.

Table 8.46 Paraquat Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	5	Widely used herbicide.
Potency	0.11	4	[PA01] Solubility in water = 70 g/100 ml at 20°C. Vapor pressure < 0.0001 Pa at 20°C, Octanol/Water partition coefficient = $10^{-4.2}$. Relative density in water = 1.25. This substance is very toxic to aquatic organisms. The substance may cause long-term effects in the aquatic environment. Carrier solvents used in commercial formulations may change physical and toxicological properties.
Persistence	0.10	4	[PA02] Paraquat is adsorbed on suspended matter and on sediment in water. If paraquat is not subject to sorption, it is rapidly degraded by microorganisms. Although paraquat could not be detected after 1 to 4 days on environmental samples, residues were still found in the biosolids after more than 400 days.
Introduction/Dispersion	0.11	5	No specialized equipment or knowledge needed
Process Removal	0.09	3	Unknown
Storability	0.07	4	[PA01] Store in well ventilated room
Outcomes	0.26	4	[PA01] Paraquat is known to be toxic to aquatic organisms. Remediation may be required.
Public Perception	0.02	2	The public does not have an usual fear of this chemical.
Composite Score		**4.2**	

Comments:

[PA01] http://www.cdc.gov/niosh/ipcsneng/neng0005.html

[PA02] http://144.16.93.203/energy/HC270799/HDL/ENV/enven/vol355.htm

Table 8.47 Paraquat Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	5	Widely used herbicide.
Potency	0.06	3	[PA01] Not combustible. Gives off irritating or toxic fumes (or gases in a fire). Boiling point (decomposes) = 300°C. Melting point = 175 to 180°C
Persistence	0.05	4	[PA02]Paraquat is adsorbed on suspended matter and on sediment in water. If paraquat is not subject to sorption, it is rapidly degraded by microorganisms. Although paraquat could not be detected after 1 to 4 days on environmental samples, residues were still found in the biosolids after more than 400
Introduction/Dispersion	0.06	5	No specialized equipment or knowledge needed
Process Removal	0.04	3	Unknown
Storability	0.02	4	[PA01]Store in well ventilated room
Outcomes	0.32	4	Remediation of collection systems and treatment facilities may be required.
Public Perception	0.29	2	The public does not have an usual fear of this chemical.
Composite Score		**3.5**	

Comments:

[PA01]http://www.cdc.gov/niosh/ipcsneng/neng0005.html

[PA02]http://144.16.93.203/energy/HC270799/HDL/ENV/enven/vol355.htm

Table 8.48 Paraquat Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	5	Widely used herbicide.
Potency	0.06	4	[PA01]Solubility in water = 70 g/100 ml at 20°C. Vapor pressure < 0.0001 Pa at 20°C, Octanol/Water partition coefficient = $10^{-4.2.}$ Relative density in water = 1.25. This substance is very toxic to aquatic organisms. The substance may cause long-term effects in the aquatic environment. Carrier solvents used in commercial formulations may change physical and toxicological properties.
Persistence	0.16	4	[PA02]Paraquat is adsorbed on suspended matter and on sediment in water. If paraquat is not subject to sorption, it is rapidly degraded by microorganisms. Although paraquat could not be detected after 1 to 4 days on environmental samples, residues were still found in the biosolids after more than 400
Introduction/Dispersion	0.03	5	No specialized equipment or knowledge needed.
Process Removal	0.16	3	Unknown
Storability	0.03	4	[PA01]Store in well ventilated room.
Outcomes	0.20	4	[PA01]This substance is very toxic to aquatic organisms.
Public Perception	0.33	2	The public does not have an usual fear of this chemical.
	Composite Score	**3.2**	

Comments:

[PA01]http://www.cdc.gov/niosh/ipcsneng/neng0005.html

[PA02]http://144.16.93.203/energy/HC270799/HDL/ENV/enven/vol355.htm

Table 8.49 Strontium-90 Worker/Public Health

Criterion	Worker/Public Health		
	Weighting Factor	Score	Comments
Availability	0.18	3	[ST01]Strontium-90 is found in the waste from nuclear reactors. It is also used as a tracer in medical and agricultural studies. Strontium-90 is also used as a power supply for remote instruments such as beacons and weather stations and in industrial instruments for measuring thicknesses.
Potency	0.16	3	[ST02]The DOE has set a limit of $2x10^{-9}$ μCi/ml of air for workplace exposure at DOE facilities
Persistence	0.04	5	[ST01] Half life of 29.1 years. Emits beta particles but no gamma rays as it decays to yttrium-90
Introduction/Dispersion	0.04	3	Could require some specialized equipment and knowledge.
Process Removal	0.02	3	[ST02]Most radioactive strontium dissolves in water
Storability	0.04	5	[ST01] Half life of 29.1 years. Emits beta particles but no gamma rays as it decays to yttrium-90
Outcomes	0.28	4	[ST02]Strontium-90 behaves like calcium and therefore collects in the bones and teeth. Lowered blood cell counts have been observed in animals that have breathed radioactive strontium. There has also been observed a thinning of the lower layer of skin of animals that have had dermal exposure to radioactive strontium
Public Perception	0.24	4	Much public fear is associated with radioactive materials
	Composite Score	**3.7**	

Comments:

[ST01] http://www.epa.gov/docs/radiation/radionuclides/strontium.htm

[ST02] http://www.atsdr.cdc.gov/toxprofiles/phs159.html

Table 8.50 Strontium-90 Process Upset

Criterion	Process Upset		
	Weighting Factor	Score	Comments
Availability	0.24	3	[ST01]Strontium-90 is found in the waste from nuclear reactors. It is also used as a tracer in medical and agricultural studies. Strontium-90 is also used as a power supply for remote instruments such as beacons and weather stations and in industrial instruments for measuring thicknesses.
Potency	0.11	3	Unknown
Persistence	0.10	5	[ST01] Half life of 29.1 years. Emits beta particles but no gamma rays as it decays to yttrium-90
Introduction/Dispersion	0.11	3	Could require some specialized equipment and knowledge.
Process Removal	0.09	3	[ST02]Most radioactive strontium dissolves in water
Storability	0.07	5	[ST01] Half life of 29.1 years. Emits beta particles but no gamma rays as it decays to yttrium-90
Outcomes	0.26	3	Unknown
Public Perception	0.02	4	Much public fear is associated with radioactive materials
Composite Score		**3.4**	

Comments:

[ST01] http://www.epa.gov/docs/radiation/radionuclides/strontium.htm

[ST02] http://www.atsdr.cdc.gov/toxprofiles/phs159.html

Table 8.51 Strontium-90 Physical Damage/Destruction

Criterion	Physical Damage/Destruction		
	Weighting Factor	Score	Comments
Availability	0.16	3	[ST01]Strontium-90 is found in the waste from nuclear reactors. It is also used as a tracer in medical and agricultural studies. Strontium-90 is also used as a power supply for remote instruments such as beacons and weather stations and in industrial instruments for measuring thicknesses.
Potency	0.06	4	Unknown
Persistence	0.05	5	[ST01] Half life of 29.1 years. Emits beta particles but no gamma rays as it decays to yttrium-90
Introduction/Dispersion	0.06	3	Could require some specialized equipment and knowledge.
Process Removal	0.04	3	[ST02]Most radioactive strontium dissolves in water
Storability	0.02	5	[ST01] Half life of 29.1 years. Emits beta particles but no gamma rays as it decays to yttrium-90
Outcomes	0.32	4	Contamination of wastewater collection and treatment systems facilities could require remediation.
Public Perception	0.29	4	Much public fear is associated with radioactive materials
Composite Score		**3.8**	

Comments:

ST01 http://www.epa.gov/docs/radiation/radionuclides/strontium.htm

ST02 http://www.atsdr.cdc.gov/toxprofiles/phs159.html

Table 8.52 Strontium-90 Pass Through

Criterion	Pass Through		
	Weighting Factor	Score	Comments
Availability	0.03	3	[ST01]Strontium-90 is found in the waste from nuclear reactors. It is also used as a tracer in medical and agricultural studies. Strontium-90 is also used as a power supply for remote instruments such as beacons and weather stations and in industrial instruments for measuring thicknesses.
Potency	0.06	4	Unknown
Persistence	0.16	5	[ST01] Half life of 29.1 years. Emits beta particles but no gamma rays as it decays to yttrium-90
Introduction/Dispersion	0.03	3	Could require some specialized equipment and knowledge.
Process Removal	0.16	3	[ST02]Most radioactive strontium dissolves in water
Storability	0.03	5	[ST01] Half life of 29.1 years. Emits beta particles but no gamma rays as it decays to yttrium-90
Outcomes	0.20	3	Decay and dilution would eventually occur in the environment.
Public Perception	0.33	4	Much public fear is associated with radioactive materials
Composite Score		**3.8**	

Comments:

ST01 http://www.epa.gov/docs/radiation/radionuclides/strontium.htm

ST02 http://www.atsdr.cdc.gov/toxprofiles/phs159.html

Table 8.53 Worker/Public Health Weighting Factors

	Availability	Potency	Persistence	Introduction/ Dispersion	Process Removal	Storability	Outcomes	Public Perception	Sum	Normalized Factor
Availability	**1.00**	**3.00**	**7.00**	**7.00**	**9.00**	**5.00**	**0.11**	**0.11**	32.22	**0.18**
Potency	**0.33**	**1.00**	**5.00**	**7.00**	**9.00**	**7.00**	**0.11**	**0.11**	29.56	**0.16**
Persistence	**0.14**	**0.20**	**1.00**	**3.00**	**1.00**	**1.00**	**0.14**	**0.20**	6.69	**0.04**
Introduction/Dispersion	**0.14**	**0.14**	**0.33**	**1.00**	**5.00**	**1.00**	**0.20**	**0.20**	8.02	**0.04**
Process Removal	**0.11**	**0.11**	**1.00**	**0.20**	**1.00**	**0.33**	**0.11**	**0.14**	3.01	**0.02**
Storability	**0.20**	**0.14**	**1.00**	**1.00**	**3.00**	**1.00**	**0.20**	**0.14**	6.69	**0.04**
Outcomes	**9.00**	**9.00**	**7.00**	**5.00**	**9.00**	**5.00**	**1.00**	**5.00**	50.00	**0.28**
Public Perception	**9.00**	**9.00**	**5.00**	**5.00**	**7.00**	**7.00**	**0.20**	**1.00**	43.20	**0.24**
								Sum	179.38	1

1	**Equal importance**
3	**Moderate importance of one over another**
5	**Strong or essential importance**
7	**Very strong or demonstrated importance**
9	**Extreme importance**

Table 8.54 Process Upset Weighting Factors

	Availability	Potency	Persistence	Introduction/ Dispersion	Process Removal	Storability	Outcomes	Public Perception	Sum	Normalized Factor
Availability	**1.00**	**3.00**	**7.00**	**7.00**	**5.00**	**5.00**	**0.20**	**5.00**	33.20	**0.24**
Potency	**0.33**	**1.00**	**1.00**	**3.00**	**3.00**	**1.00**	**0.20**	**5.00**	14.53	**0.11**
Persistence	**0.14**	**1.00**	**1.00**	**3.00**	**3.00**	**1.00**	**0.20**	**5.00**	14.34	**0.10**
Introduction/Dispersion	**0.14**	**0.33**	**0.33**	**1.00**	**5.00**	**3.00**	**0.20**	**5.00**	15.01	**0.11**
Process Removal	**0.20**	**0.33**	**0.33**	**0.20**	**1.00**	**5.00**	**0.20**	**5.00**	12.27	**0.09**
Storability	**0.20**	**1.00**	**1.00**	**0.33**	**0.20**	**1.00**	**0.20**	**5.00**	8.93	**0.07**
Outcomes	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**	**1.00**	**5.00**	36.00	**0.26**
Public Perception	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**1.00**	2.40	**0.02**
								Sum	136.69	1

1	**Equal importance**
3	**Moderate importance of one over another**
5	**Strong or essential importance**
7	**Very strong or demonstrated importance**
9	**Extreme importance**

Table 8.55 Physical Damage/Destruction Weighting Factors

	Availability	Potency	Persistence	Introduction/ Dispersion	Process Removal	Storability	Outcomes	Public Perception	Sum	Normalized Factor
Availability	**1.00**	**3.00**	**7.00**	**7.00**	**5.00**	**5.00**	**0.11**	**0.14**	28.25	**0.16**
Potency	**0.33**	**1.00**	**1.00**	**3.00**	**3.00**	**1.00**	**0.11**	**0.14**	9.59	**0.06**
Persistence	**0.14**	**1.00**	**1.00**	**3.00**	**3.00**	**1.00**	**0.11**	**0.14**	9.40	**0.05**
Introduction/Dispersion	**0.14**	**0.33**	**0.33**	**1.00**	**5.00**	**3.00**	**0.11**	**0.14**	10.06	**0.06**
Process Removal	**0.20**	**0.33**	**0.33**	**0.20**	**1.00**	**5.00**	**0.11**	**0.14**	7.32	**0.04**
Storability	**0.20**	**1.00**	**1.00**	**0.33**	**0.20**	**1.00**	**0.11**	**0.14**	3.99	**0.02**
Outcomes	**9.00**	**9.00**	**9.00**	**9.00**	**9.00**	**9.00**	**1.00**	**0.14**	55.14	**0.32**
Public Perception	**7.00**	**7.00**	**7.00**	**7.00**	**7.00**	**7.00**	**7.00**	**1.00**	50.00	**0.29**
								Sum	173.75	1

1	**Equal importance**
3	**Moderate importance of one over another**
5	**Strong or essential importance**
7	**Very strong or demonstrated importance**
9	**Extreme importance**

Table 8.56 Process Upset Weighting Factors

	Availability	Potency	Persistence	Introduction/ Dispersion	Process Removal	Storability	Outcomes	Public Perception	Sum	Normalized Factor
Availability	1.00	0.50	0.14	1.00	0.14	1.00	0.20	0.14	4.13	0.03
Potency	5.00	1.00	0.50	1.00	0.33	1.00	0.20	0.14	9.18	0.06
Persistence	7.00	5.00	1.00	7.00	1.00	3.00	0.20	0.14	24.34	0.16
Introduction/Dispersion	1.00	1.00	0.14	1.00	0.20	1.00	0.20	0.14	4.69	0.03
Process Removal	7.00	3.00	1.00	5.00	1.00	7.00	0.20	0.14	24.34	0.16
Storability	1.00	1.00	0.33	1.00	0.14	1.00	0.20	0.14	4.82	0.03
Outcomes	5.00	5.00	5.00	5.00	5.00	5.00	1.00	0.14	31.14	0.20
Public Perception	7.00	7.00	7.00	7.00	7.00	7.00	7.00	1.00	50.00	0.33
									152.64	1

1	Equal importance
3	Moderate importance of one over another
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance

Table 8.57 Round 1, Experiment 1 Results

All samples were collected on 9/27/05

Spiked @ 1 ppb	***Cis* 1,2-dichloroethylene ppb**	**Benzene ppb**	**Ethylbenzene ppb**	***p*-xylene ppb**
Distilled	2.26	1.2	1.52	1.45
Drinking Water	1.93	0.850	0.895	1.310
River Water	1.87	0.884	0.800	0.756
Secondary Effluent	1.85	0.840	0.755	0.805
Primary Effluent	2.02	0.920	0.890	0.916
Mixed Liquor	1.75	0.727	0.555	0.562

Spiked @ 10 ppb	***Cis* 1,2-dichloroethylene ppb**	**Benzene ppb**	**Ethylbenzene ppb**	***p*-xylene ppb**
Distilled	7.31	6.95	6.13	5.34
Drinking Water	7.04	6.97	6.19	6.15
River Water	6.90	6.33	6.06	5.51
Secondary Effluent	6.50	6.44	5.56	5.10
Primary Effluent	5.09	4.51	4.03	3.69
Mixed Liquor	9.13	9.19	6.66	5.95

Spiked @ 50 ppb	***Cis* 1,2-dichloroethylene ppb**	**Benzene ppb**	**Ethylbenzene ppb**	***p*-xylene ppb**
Distilled	48.1	63.6	70.4	76.4
Drinking Water	44.8	55.2	58.0	63.4
River Water	35.1	44.6	45.8	46.3
Secondary Effluent	34.1	44.2	45.0	44.8
Primary Effluent	36.9	48.6	48.0	46.7
Mixed Liquor	30.5	37.9	29.1	27.2

Table 8.58 Round 1, Experiment 2 Results

All Wastewater samples were collected on 10/10/05
River and Drinking Water were collected on 10/6/05

Spiked @ 1 ppb	***Cis* 1,2-dichloroethylene**	**Benzene**	**Ethylbenzene**	***p*-xylene**
	ppb	**ppb**	**ppb**	**ppb**
Distilled	0.798	1.71	2.19	2.93
Drinking Water	1.08	1.99	2.51	PTL
River Water	1.12	2.07	2.52	3.15
Secondary Effluent	0.778	1.76	2.22	2.96
Primary Effluent	0.389	1.48	2.04	2.80
Mixed Liquor	0.993	1.80	2.28	2.96

Spiked @ 10 ppb	***Cis* 1,2-dichloroethylene**	**Benzene**	**Ethylbenzene**	***p*-xylene**
	ppb	**ppb**	**ppb**	**ppb**
Distilled	9.94	9.00	9.69	9.03
Drinking Water	10.1	8.90	9.23	9.11
River Water	10.2	9.13	9.46	9.05
Secondary Effluent	7.39	6.80	6.91	6.80
Primary Effluent	4.87	4.93	5.01	5.18
Mixed Liquor	9.95	8.74	7.85	7.37

Spiked @ 50 ppb	***Cis* 1,2-dichloroethylene**	**Benzene**	**Ethylbenzene**	***p*-xylene**
	ppb	**ppb**	**ppb**	**ppb**
Distilled	53.5	50.8	56.3	57.2
Drinking Water	41.2	38.6	38.3	39.6
River Water	42.1	39.9	41.1	40.6
Secondary Effluent	33.3	30.6	30.7	30.6
Primary Effluent	23.2	21.0	19.8	19.4
Mixed Liquor	42.3	40.8	33.7	32.2

PTL = Purity Too Low

Table 8.59 Round 1, Experiment 3 Results

All Wastewater samples were collected on 10/10/05
River and Drinking Water were collected on 10/6/05

Spiked @ 1 ppb	***Cis* 1,2-dichloroethylene**	**Benzene**	**Ethylbenzene**	***p*-xylene**
	ppb	**ppb**	**ppb**	**ppb**
Distilled	-0.168	2.36	1.90	2.47
Drinking Water	0.534	2.83	2.29	3.17
River Water	-0.539	2.14	1.67	2.29
Secondary Effluent	-0.649	2.13	1.65	2.32
Primary Effluent	-0.634	2.06	1.61	2.26
Mixed Liquor	0.525	2.92	2.25	2.85

Spiked @ 10 ppb	***Cis* 1,2-dichloroethylene**	**Benzene**	**Ethylbenzene**	***p*-xylene**
	ppb	**ppb**	**ppb**	**ppb**
Distilled	12.8	12.1	10.6	10.4
Drinking Water	10.1	10.1	8.44	9.09
River Water	10.1	9.53	8.17	8.30
Secondary Effluent	7.37	7.62	6.22	6.44
Primary Effluent	4.29	5.16	4.04	4.42
Mixed Liquor	11.7	10.9	7.63	7.65

Spiked @ 50 ppb	***Cis* 1,2-dichloroethylene**	**Benzene**	**Ethylbenzene**	***p*-xylene**
	ppb	**ppb**	**ppb**	**ppb**
Distilled	49.7	47.8	44.6	42.6
Drinking Water	46.7	41.2	39.2	40.9
River Water	48.9	45.6	43.7	44.2
Secondary Effluent	46.9	44.0	40.8	39.3
Primary Effluent	27.0	24.9	22.3	20.5
Mixed Liquor	50.9	47.5	30.4	27.4

PTL = Purity Too Low

Table 8.60 Round 1, Experiment 4 Results

All Wastewater samples were collected on 10/10/05
River and Drinking Water were collected on 10/6/05

Spiked @ 1 ppb	***Cis* 1,2-dichloroethylene**	**Benzene**	**Ethylbenzene**	***p*-xylene**
	ppb	**ppb**	**ppb**	**ppb**
Distilled	-0.710	2.06	1.60	2.24
Drinking Water	-0.802	2.14	1.65	2.50
River Water	-0.694	2.13	1.63	2.28
Secondary Effluent	-0.938	2.01	1.54	2.27
Primary Effluent	-0.796	2.06	1.56	2.22
Mixed Liquor	-0.834	2.01	1.48	2.17

Spiked @ 10 ppb	***Cis* 1,2-dichloroethylene**	**Benzene**	**Ethylbenzene**	***p*-xylene**
	ppb	**ppb**	**ppb**	**ppb**
Distilled	4.45	5.82	4.40	4.66
Drinking Water	4.82	6.21	4.82	5.49
River Water	5.77	6.61	5.30	5.63
Secondary Effluent	4.92	6.13	4.83	5.30
Primary Effluent	5.10	6.10	4.55	4.97
Mixed Liquor	5.54	6.57	4.50	4.88

Spiked @ 50 ppb	***Cis* 1,2-dichloroethylene**	**Benzene**	**Ethylbenzene**	***p*-xylene**
	ppb	**ppb**	**ppb**	**ppb**
Distilled	60.4	54.5	51.1	51.9
Drinking Water	43.3	40.9	36.4	37.1
River Water	34.7	31.3	27.6	27.2
Secondary Effluent	46.5	42.7	37.8	38.4
Primary Effluent	32.9	29.6	24.2	23.3
Mixed Liquor	58.7	50.9	33.0	30.5

PTL = Purity Too Low

Table 8.61 Round 2, Experiment 1 Results

All Samples Collected 11/1/05

Spiked @ 1 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	-	2.18	2.32	1.98	2.59
Drinking Water	-	2.8	3.05	2.6	3.24
River Water	-	2.2	2.63	2	2.65
Secondary Effluent	-	2.82	3.24	2.55	3.06
Primary Effluent	-	1.84	2.34	1.43	2.28
Mixed Liquor	-	2.4	2.72	1.88	2.57

Spiked @ 10 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	9.88	8.44	7.96	8.28	9.79
Drinking Water	-	5.58	5.64	5.24	6.71
River Water	NOIS	9.5	10.3	8.53	10.3
Secondary Effluent	-	5.41	5.68	4.57	5.65
Primary Effluent	-	4.63	5.06	4.03	4.61
Mixed Liquor	15.7	10.3	10.6	9.07	9.77

Spiked @ 30 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	20.3	23.3	23.3	22.9	24.2
Drinking Water	21.8	28.4	28.2	28.3	29.7
River Water	NOIS	21.4	22.2	21.4	22.2
Secondary Effluent	22.4	33.3	32.5	31.8	32.8
Primary Effluent	18.4	23.1	23.1	21.9	23.4
Mixed Liquor	22.5	22.3	22.1	19.5	20.1

NOIS = No Internal Standard Found
- = No reported Concentration

Table 8.62 Round 2, Experiment 2 Results

All Samples Collected 11/1/05

Spiked @ 1 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	-	1.21	1.49	0.493	0.0125
Drinking Water	-	1.49	1.64	0.963	1.19
River Water	-	1.74	2.27	1.38	1.96
Secondary Effluent	-	1.6	1.84	1.12	1.23
Primary Effluent	-	1.26	1.62	0.765	1.15
Mixed Liquor	-	1.33	1.57	0.769	1.21

Spiked @ 10 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	12.2	12.7	12.4	11.8	13.1
Drinking Water	12.2	12.2	12.6	11.8	12
River Water	8.88	6.5	7.13	5.39	5.91
Secondary Effluent	6.88	4.48	4.69	3.67	3.81
Primary Effluent	9.1	5.77	6.14	4.94	5.39
Mixed Liquor	-	4.62	4.94	3.18	3.42

Spiked @ 30 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	15.4	16.2	16.3	16	16.5
Drinking Water	22.1	31	31.4	30.2	29.3
River Water	NOIS	18.7	19.3	17.5	17.8
Secondary Effluent	15.9	19.2	19.5	18.1	17.8
Primary Effluent	16.9	20.3	20.4	18.5	18.6
Mixed Liquor	22.1	17.6	18	14	12.5

NOIS = No Internal Standard Found
- = No reported Concentration

Table 8.63 Round 2, Experiment 3 Results

All Samples Collected 11/1/05

Spiked @ 1 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	---	1.63	1.77	0.864	0.702
Drinking Water	---	2.33	2.42	1.71	2.22
River Water	---	1.51	1.99	0.963	1.46
Secondary Effluent	---	1.67	1.84	1.23	1.81
Primary Effluent	---	1.99	2.45	1.56	2.17
Mixed Liquor	---	1.22	1.57	0.682	1.04

Spiked @ 10 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	12.3	15.8	15.7	15	17.1
Drinking Water	---	8.87	8.98	8.3	9.87
River Water	NOIS	9.35	8.99	8.9	9.66
Secondary Effluent	---	6.49	6.15	5.66	7.24
Primary Effluent	---	7.57	7.77	6.62	8.07
Mixed Liquor	---	11.6	10.7	10.9	14.2

Spiked @ 30 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	17.4	24.9	25.4	25.5	26.6
Drinking Water	16.8	26.1	26.3	26.9	27.9
River Water	NOIS	29.8	30.2	27.7	30.7
Secondary Effluent	13.4	18.5	18.4	18	19.5
Primary Effluent	12.2	19.7	18.2	17.7	19.9
Mixed Liquor	18.7	18.5	18.7	16.6	19.1

NOIS = No Internal Standard Found
- = No reported Concentration

Table 8.64 Round 2, Experiment 4 Results

All Samples Collected 11/1/05

Spiked @ 1 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	---	1.5	1.62	0.806	0.484
Drinking Water	---	1.48	1.61	0.875	1.11
River Water	---	1.63	1.83	1.36	2.01
Secondary Effluent	---	1.99	2.06	1.27	1.07
Primary Effluent	---	2.37	2.44	1.93	2.73
Mixed Liquor	---	1.25	1.53	0.627	0.719

Spiked @ 10 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	---	2.76	2.66	2.19	2.5
Drinking Water	---	3.27	3.01	3.09	3.7
River Water	---	5.59	5.06	6.29	8.35
Secondary Effluent	---	6.76	6.32	6.69	7.61
Primary Effluent	---	6.71	5.81	6.7	8.21
Mixed Liquor	---	2.75	2.75	2.11	2.42

Spiked @ 30 ppb	Trans 1,2-dichloroethylene	Styrene	o-xylene	4 chlorotoluene	1,3 DCB
	ppb	ppb	ppb	ppb	ppb
Distilled	---	8.98	7.56	9.87	12.9
Drinking Water	---	10.7	9.13	12	15.7
River Water	---	8.07	7.04	9.19	12.6
Secondary Effluent	---	14.2	12.5	14.3	17.5
Primary Effluent	---	10.2	9.48	10.7	11.8
Mixed Liquor	---	12.9	11.6	13.6	16.7

NOIS = No Internal Standard Found
- = No reported Concentration

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